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Lee et al.

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(54) **POWER DEVICE AND METHOD OF MANUFACTURING THE SAME**

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Related U.S. Application Data

(60) Division of application No. 14/316,248, filed on Jun. 26, 2014, now Pat. No. 9,685,335, which is a (Continued)

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Dec. 23, 2013 (KR) 10-2013-0161778

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H01L 21/331 (2006.01)
H01L 21/8222 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01L 29/66348*** (2013.01); ***H01L 21/266*** (2013.01); ***H01L 21/26513*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01L 29/66348; H01L 29/66333
(Continued)

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(57) **ABSTRACT**

Provided are a power device having an improved field stop layer and a method of manufacturing the same. The method can include performing a first ion implant process by implanting impurity ions of a first conductive type into a front surface of a semiconductor substrate to form an implanted field stop layer where the semiconductor substrate is the first conductive type. The method can include performing a second ion implant process by implanting impurity ions of the first conductive type into a first part of the implanted field stop layer such that an impurity concentration of the first part of the implanted field stop layer is higher
(Continued)

than an impurity concentration of a second part of the implanted field stop layer.

20 Claims, 25 Drawing Sheets

Related U.S. Application Data

continuation-in-part of application No. 13/868,629, filed on Apr. 23, 2013, now abandoned.

(60) Provisional application No. 61/840,444, filed on Jun. 27, 2013.

(51) **Int. Cl.**

H01L 29/66	(2006.01)
H01L 21/265	(2006.01)
H01L 29/06	(2006.01)
H01L 29/10	(2006.01)
H01L 21/304	(2006.01)
H01L 29/08	(2006.01)
H01L 21/266	(2006.01)
H01L 29/423	(2006.01)
H01L 29/739	(2006.01)

(52) **U.S. Cl.**
CPC ***H01L 21/304*** (2013.01); ***H01L 29/0615*** (2013.01); ***H01L 29/0619*** (2013.01); ***H01L 29/0696*** (2013.01); ***H01L 29/0804*** (2013.01); ***H01L 29/0821*** (2013.01); ***H01L 29/1004*** (2013.01); ***H01L 29/1095*** (2013.01); ***H01L 29/4236*** (2013.01); ***H01L 29/66333*** (2013.01); ***H01L 29/7397*** (2013.01)

(58) **Field of Classification Search**
USPC 257/487, E29.262, E29.198; 438/309
See application file for complete search history.

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FIG. 1

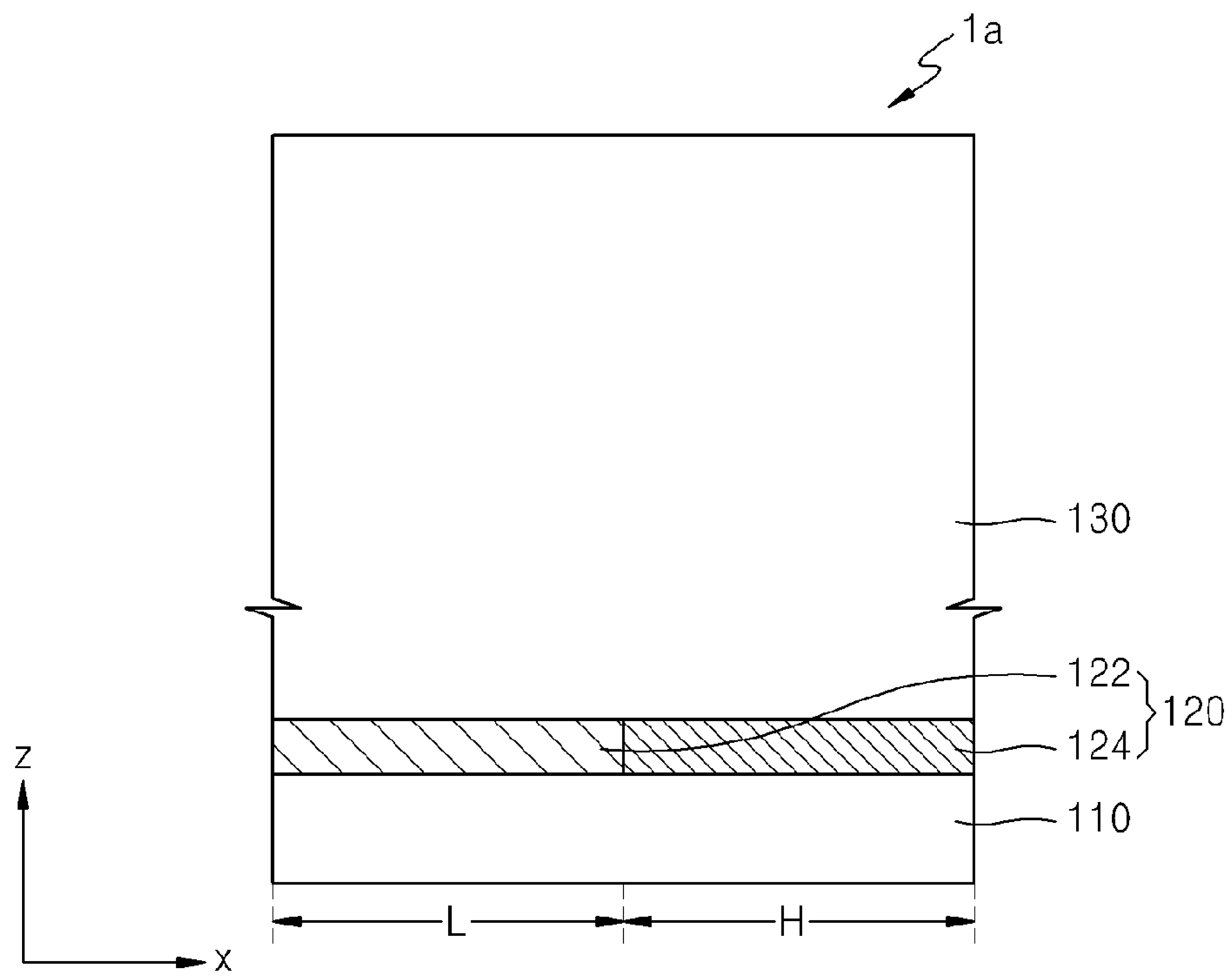


FIG. 2

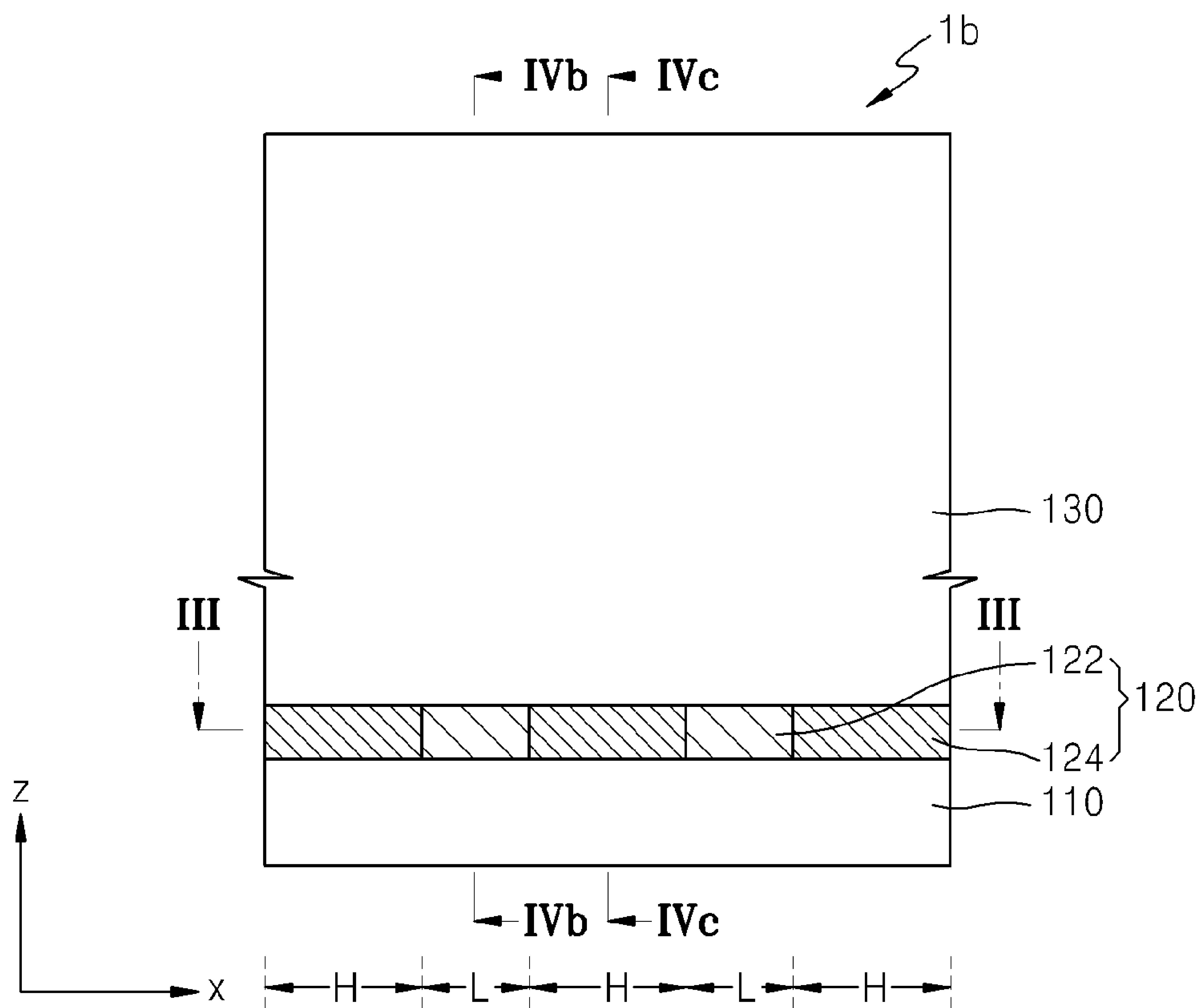


FIG. 3A

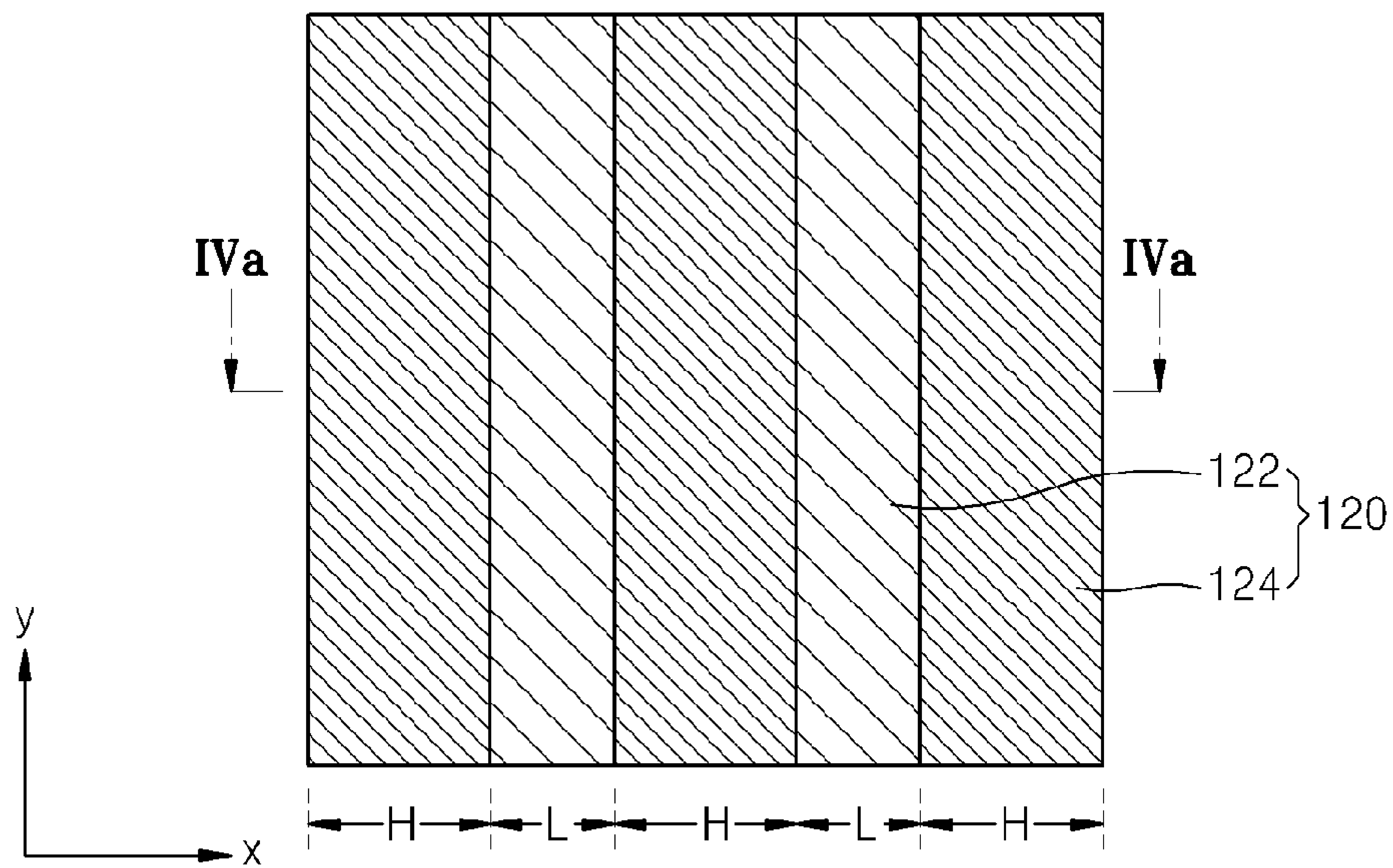


FIG. 3B

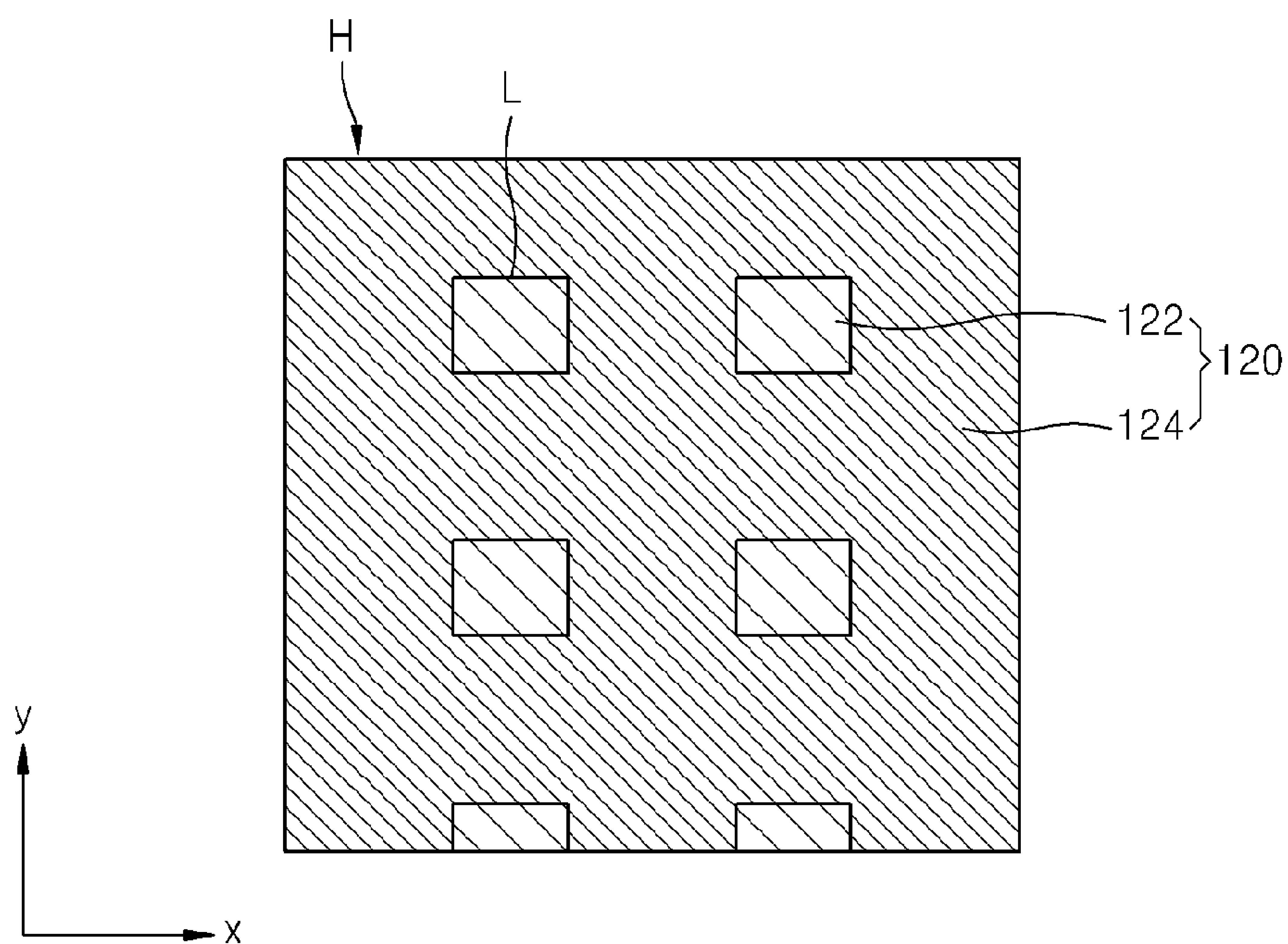


FIG. 4A

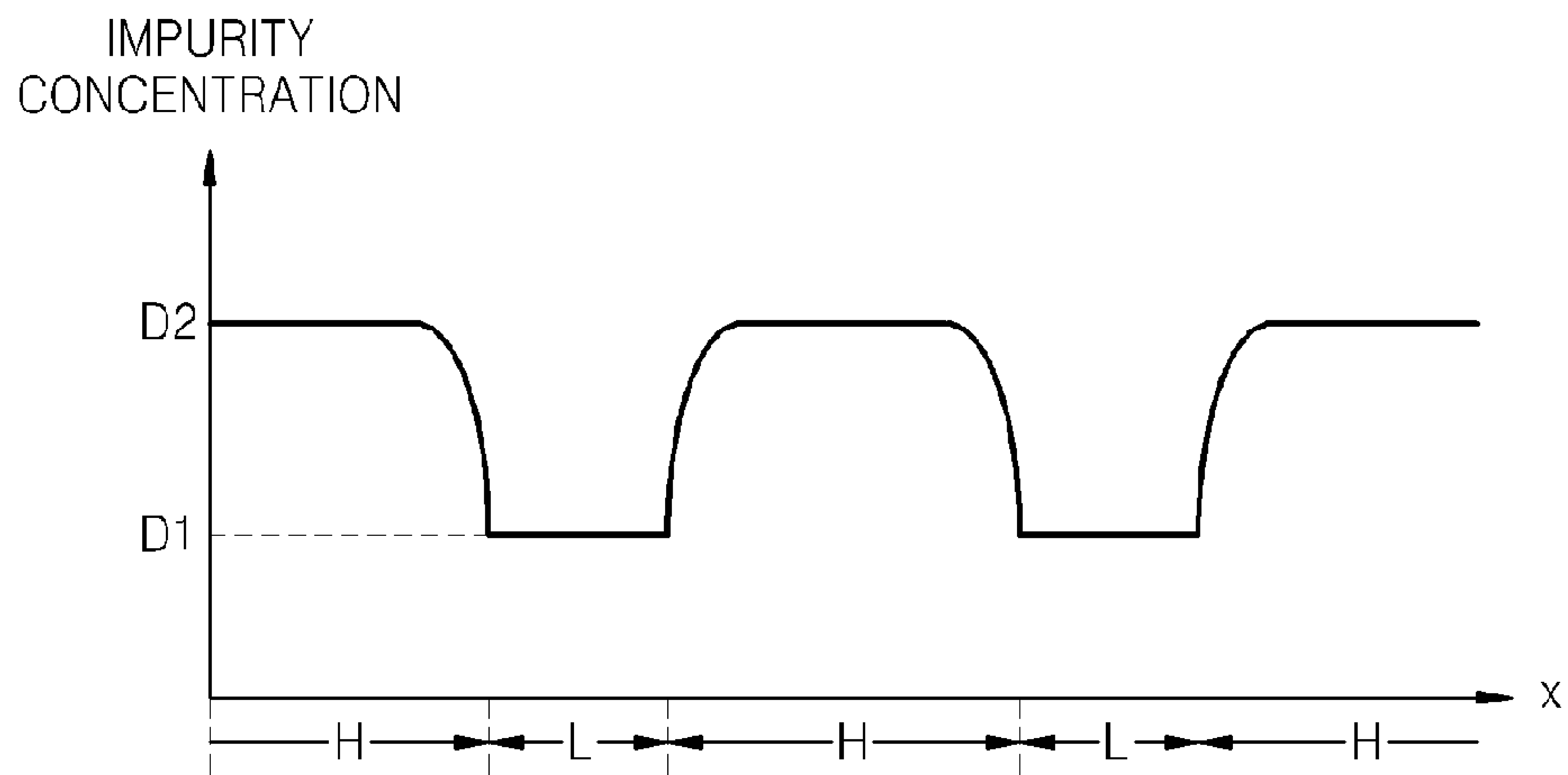


FIG. 4B

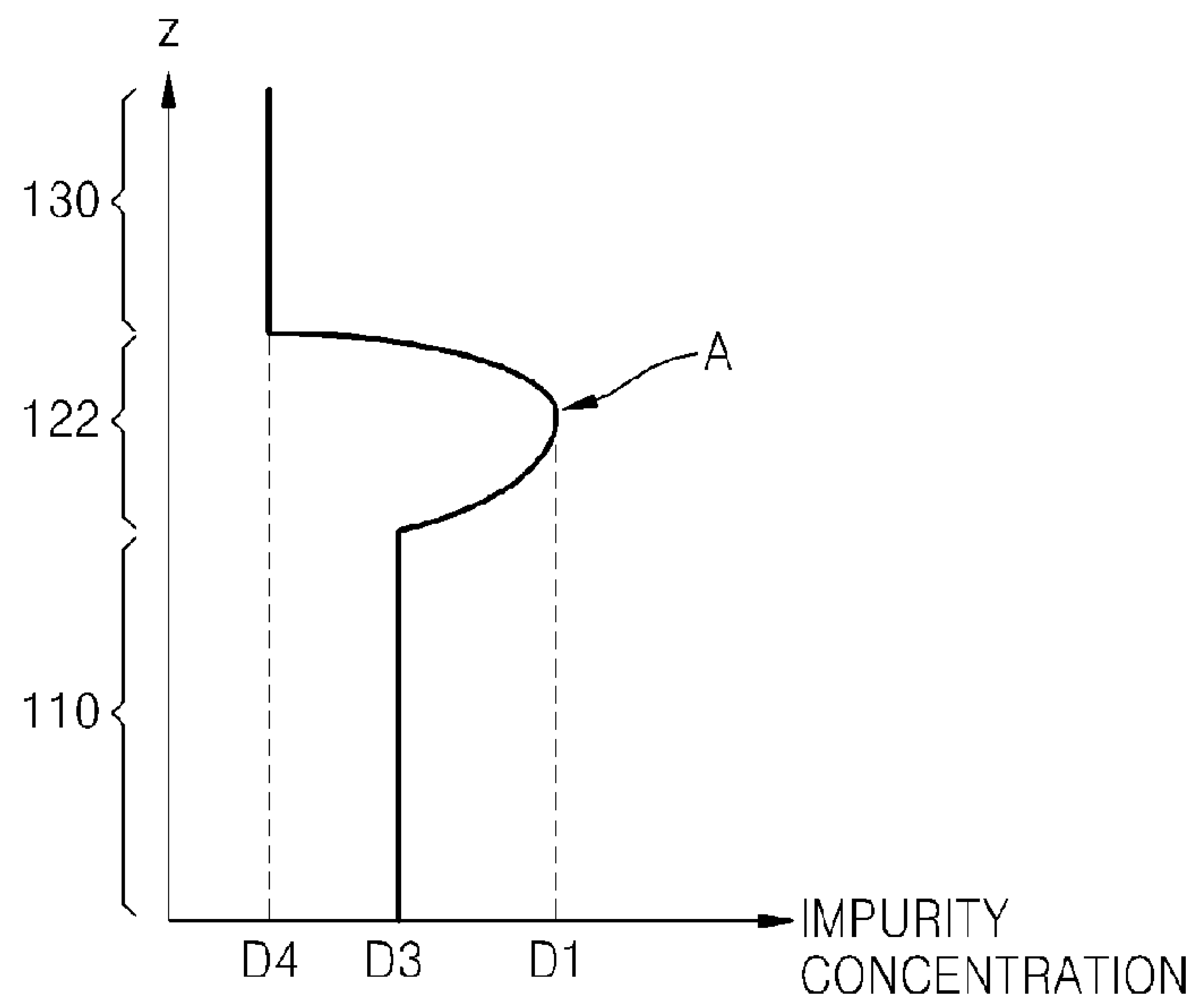


FIG. 4C

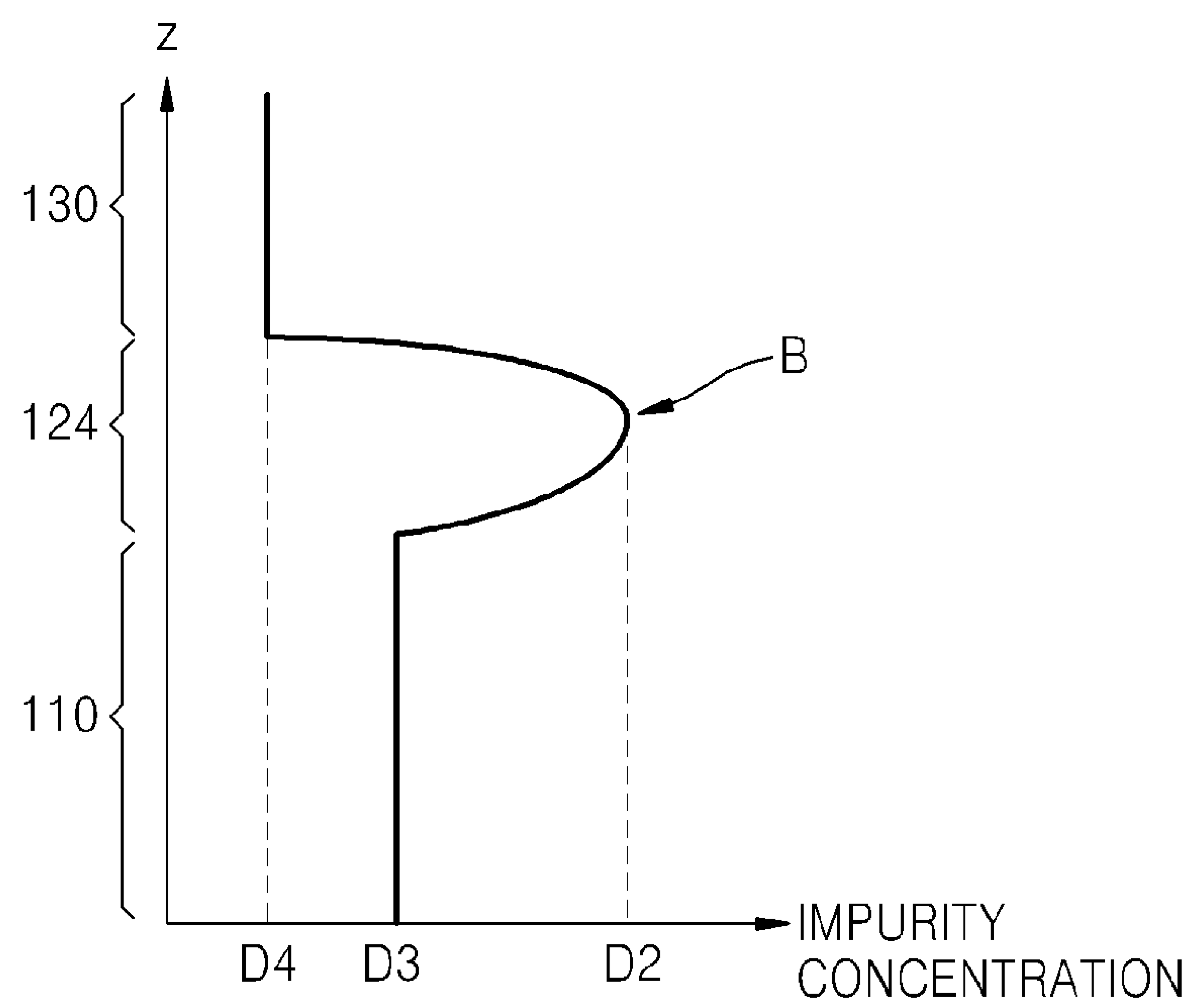


FIG. 5A

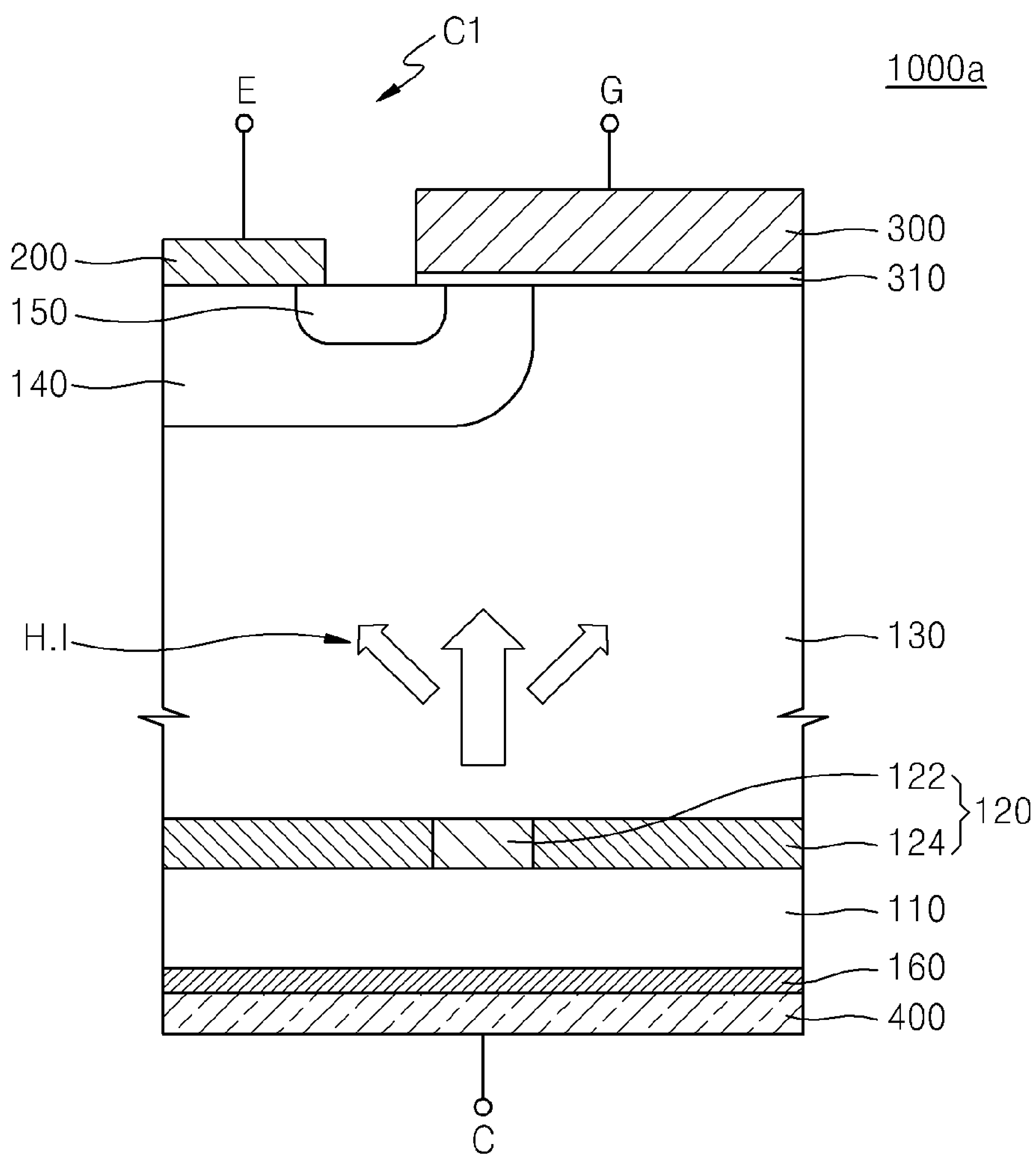


FIG. 5B

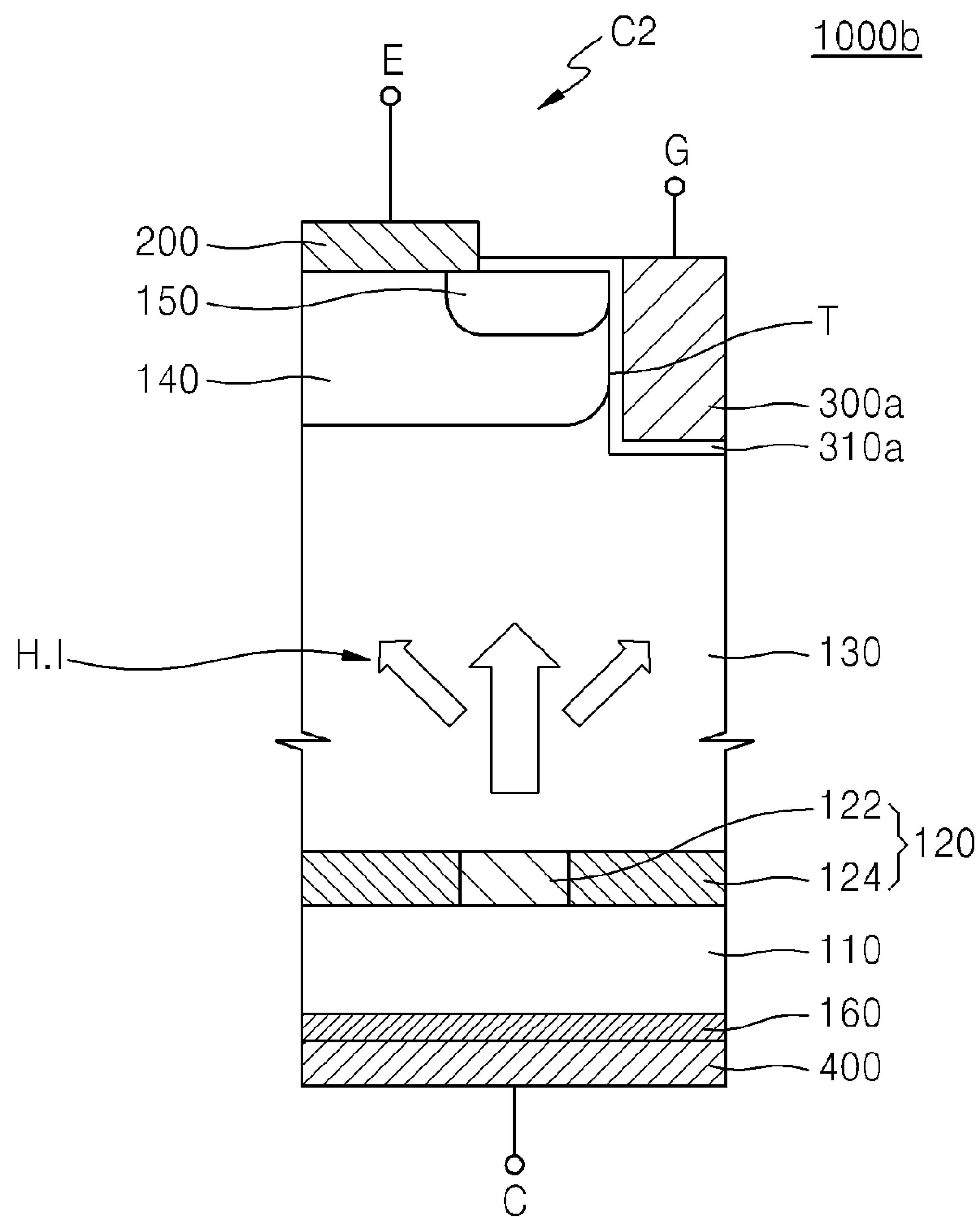


FIG. 6

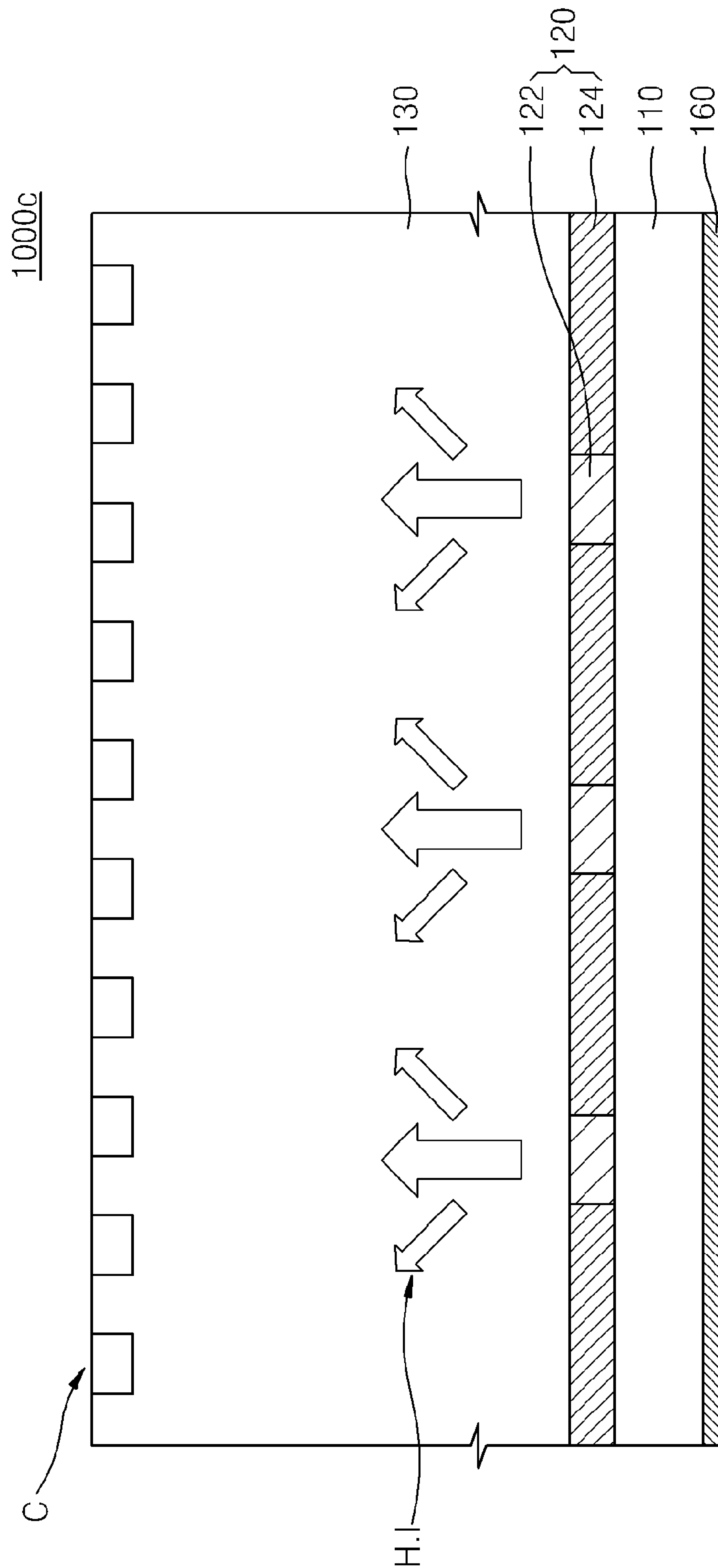


FIG. 7A

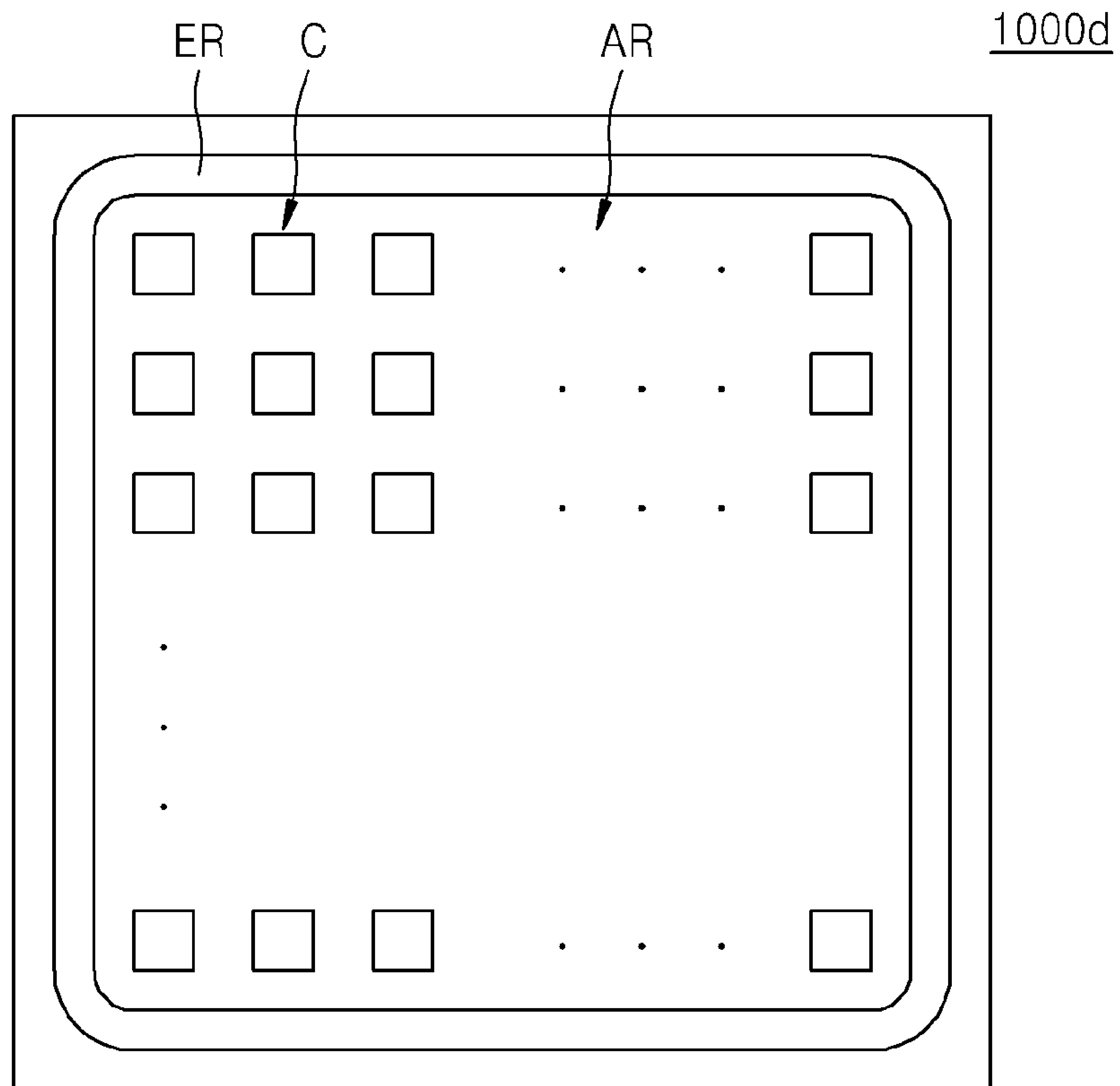


FIG. 7B

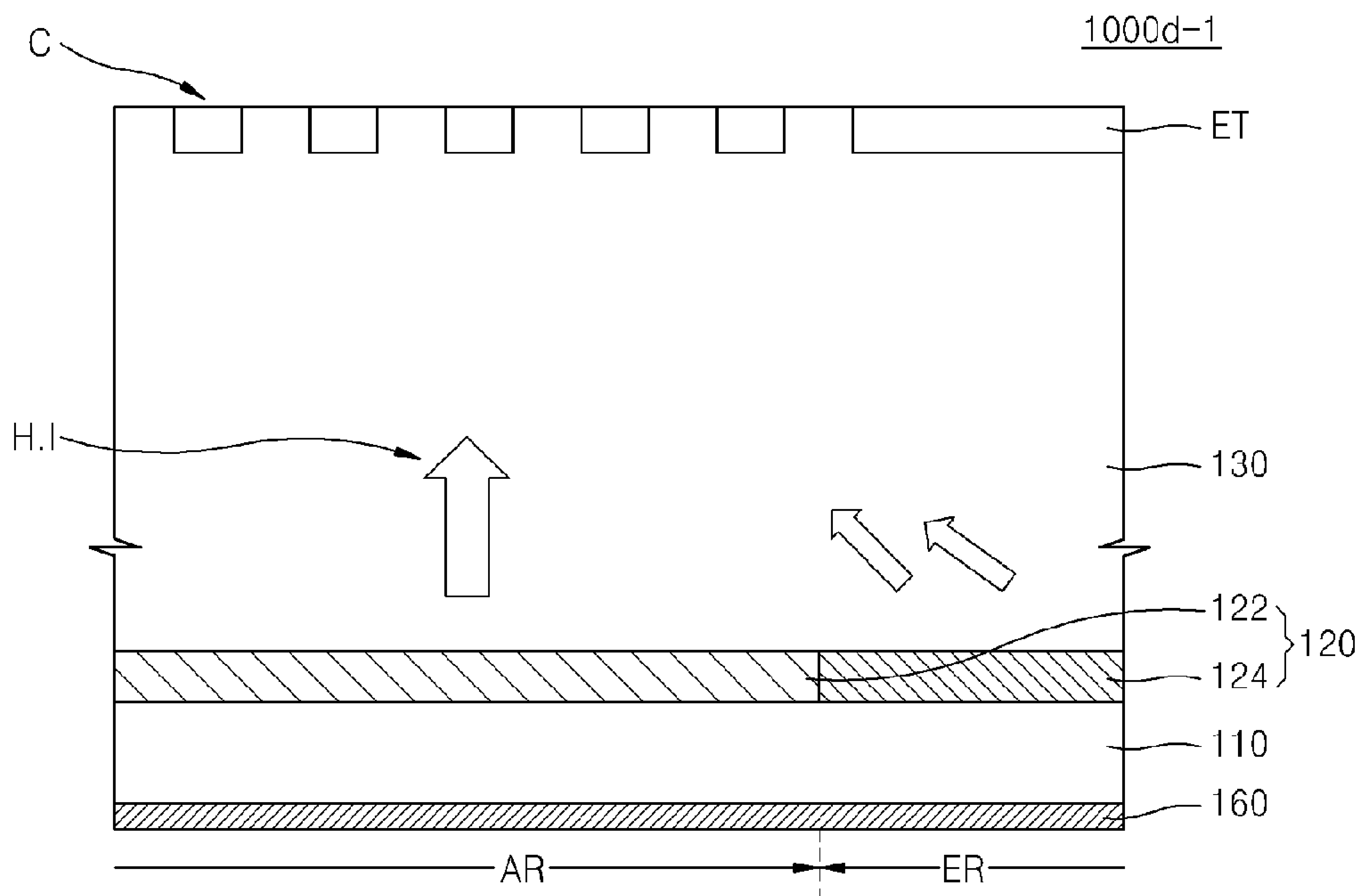


FIG. 7C

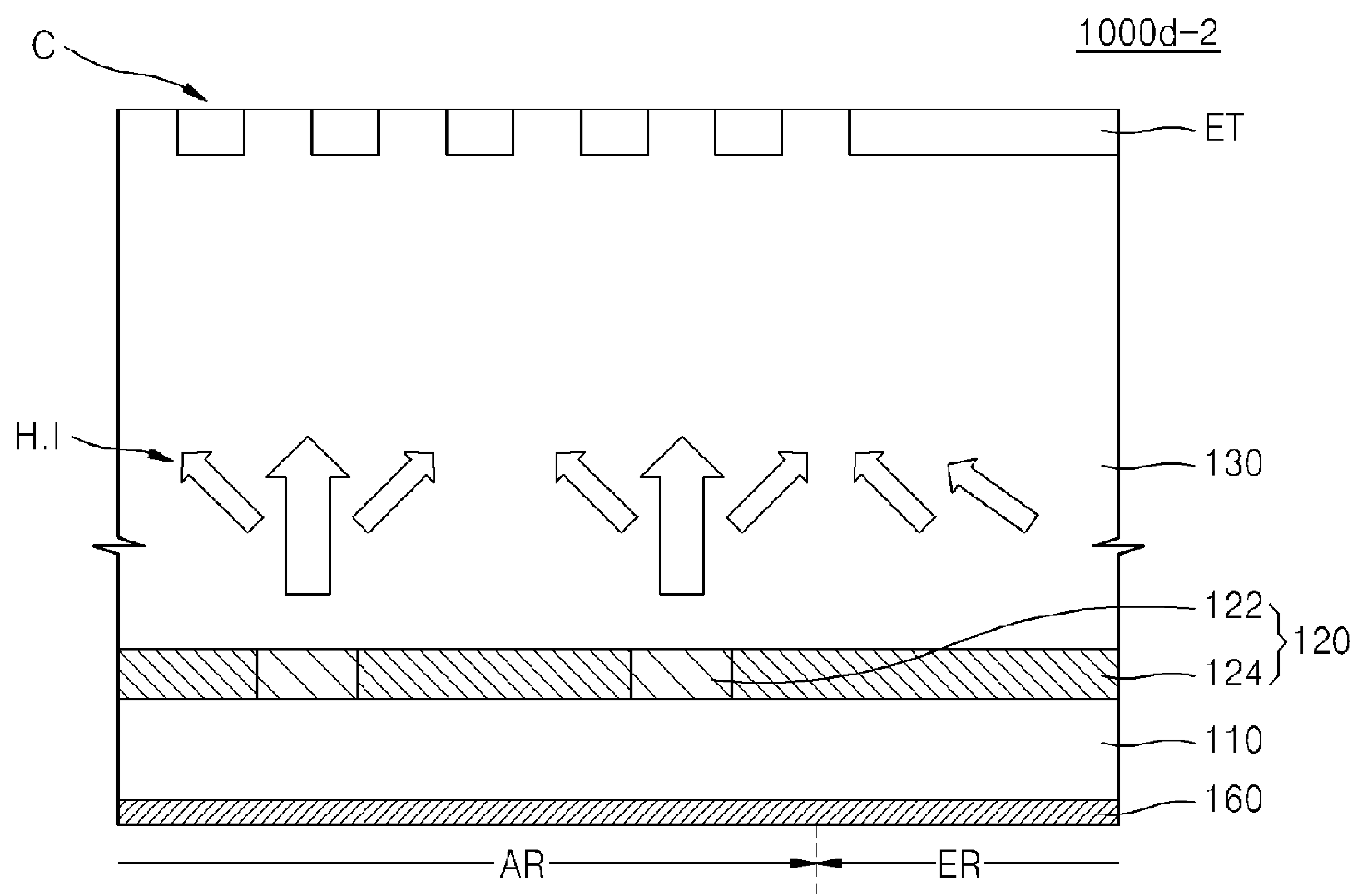


FIG. 8

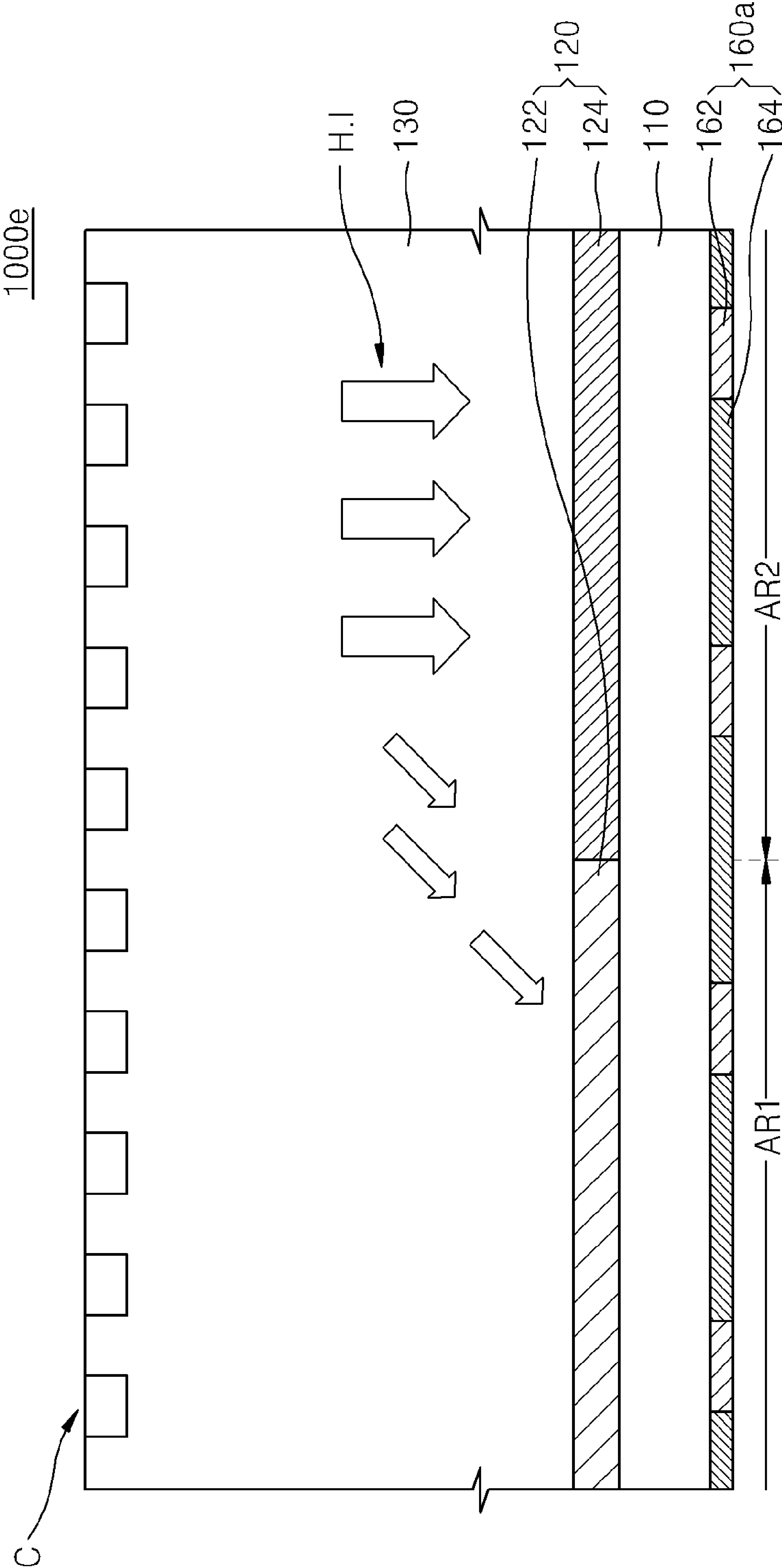


FIG. 9

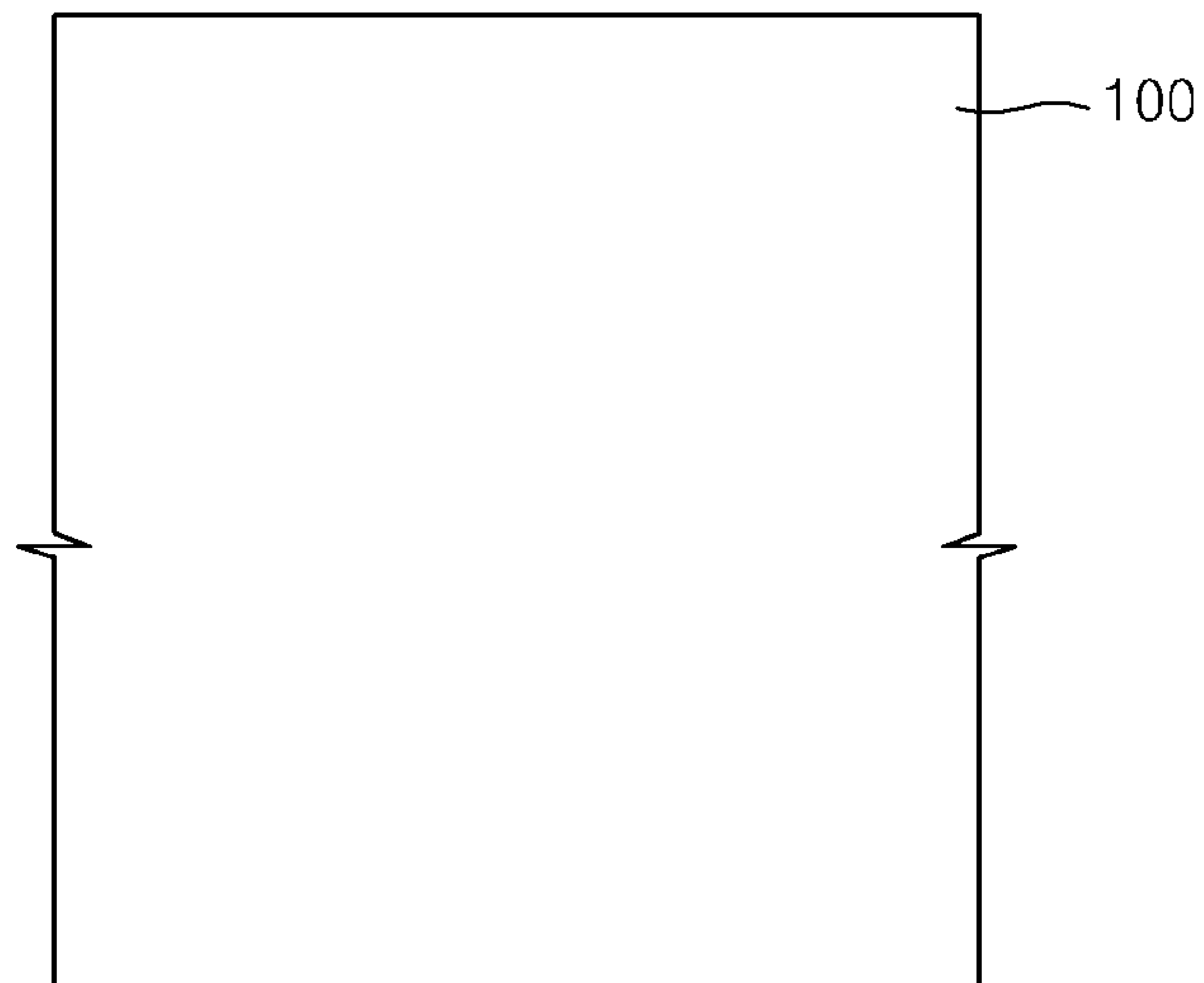


FIG. 10

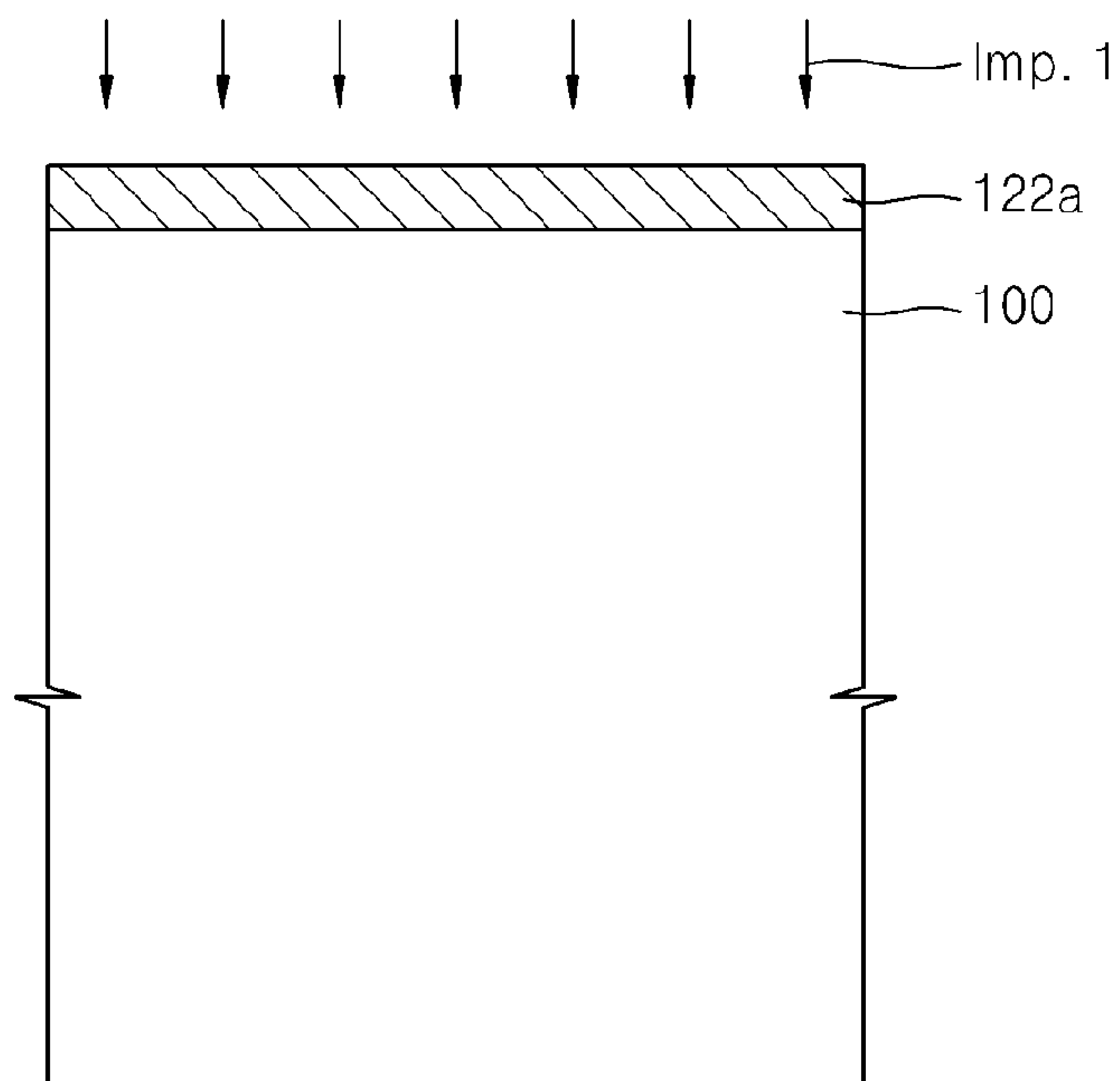


FIG. 11

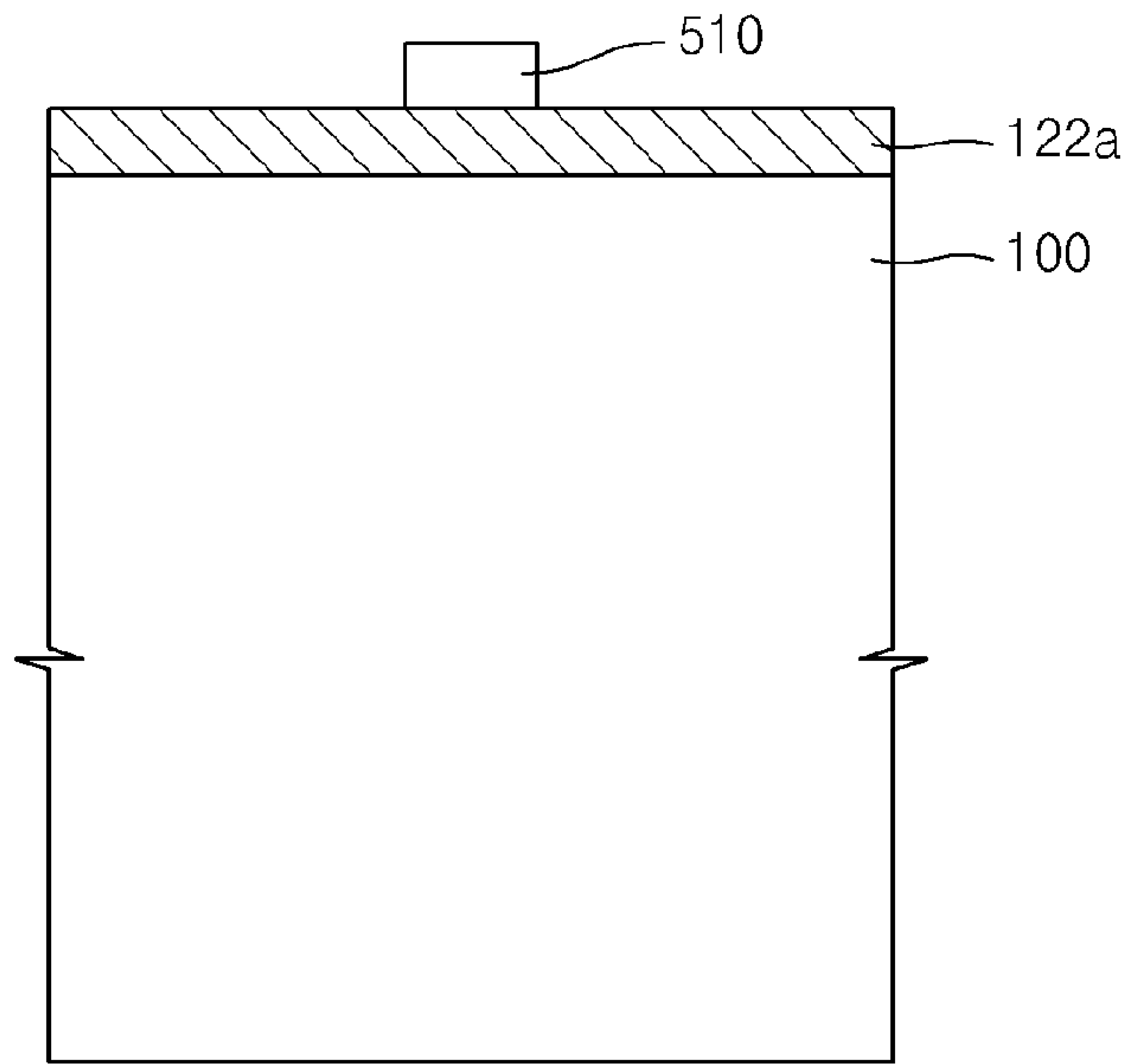


FIG. 12

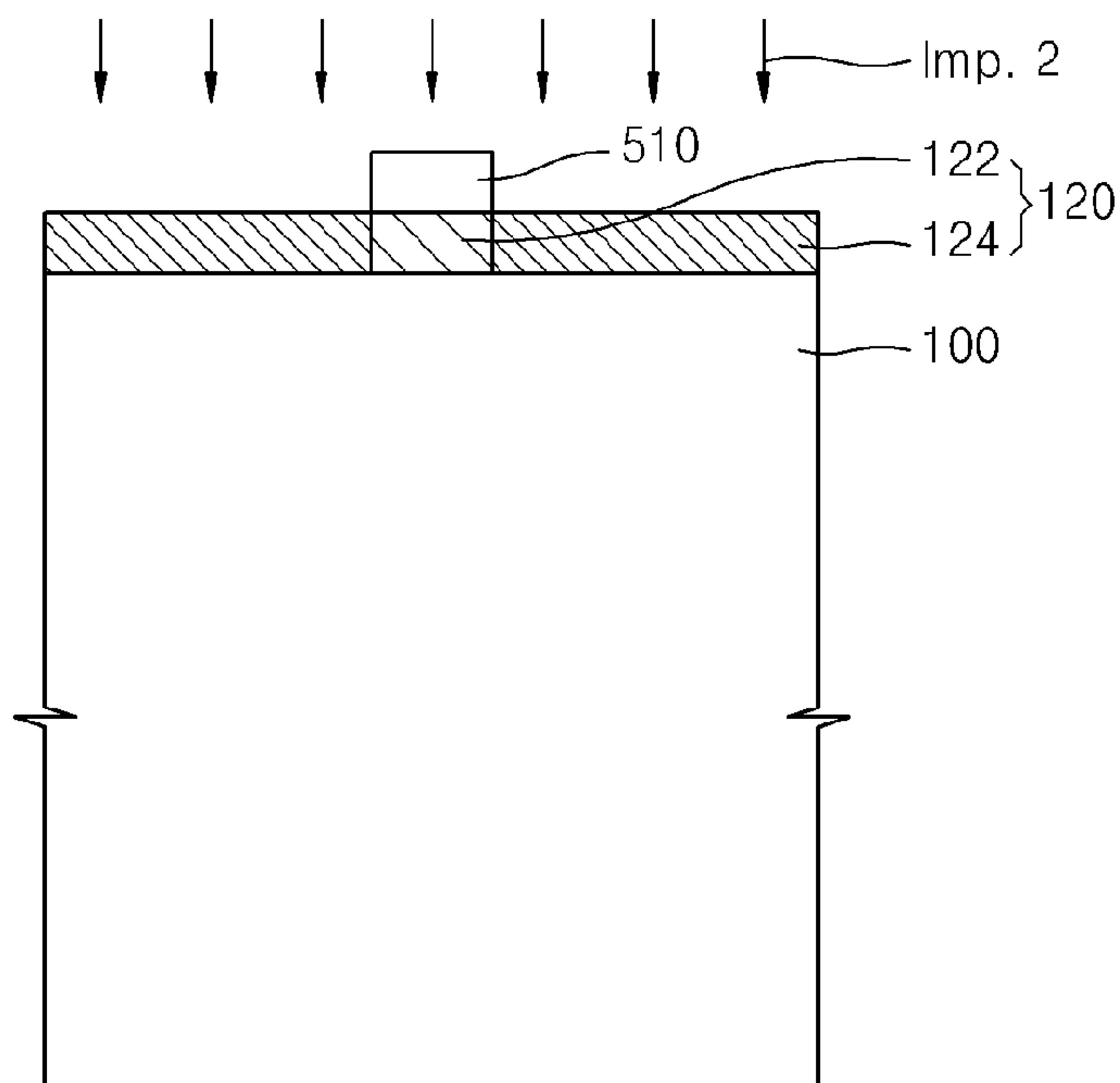


FIG. 13

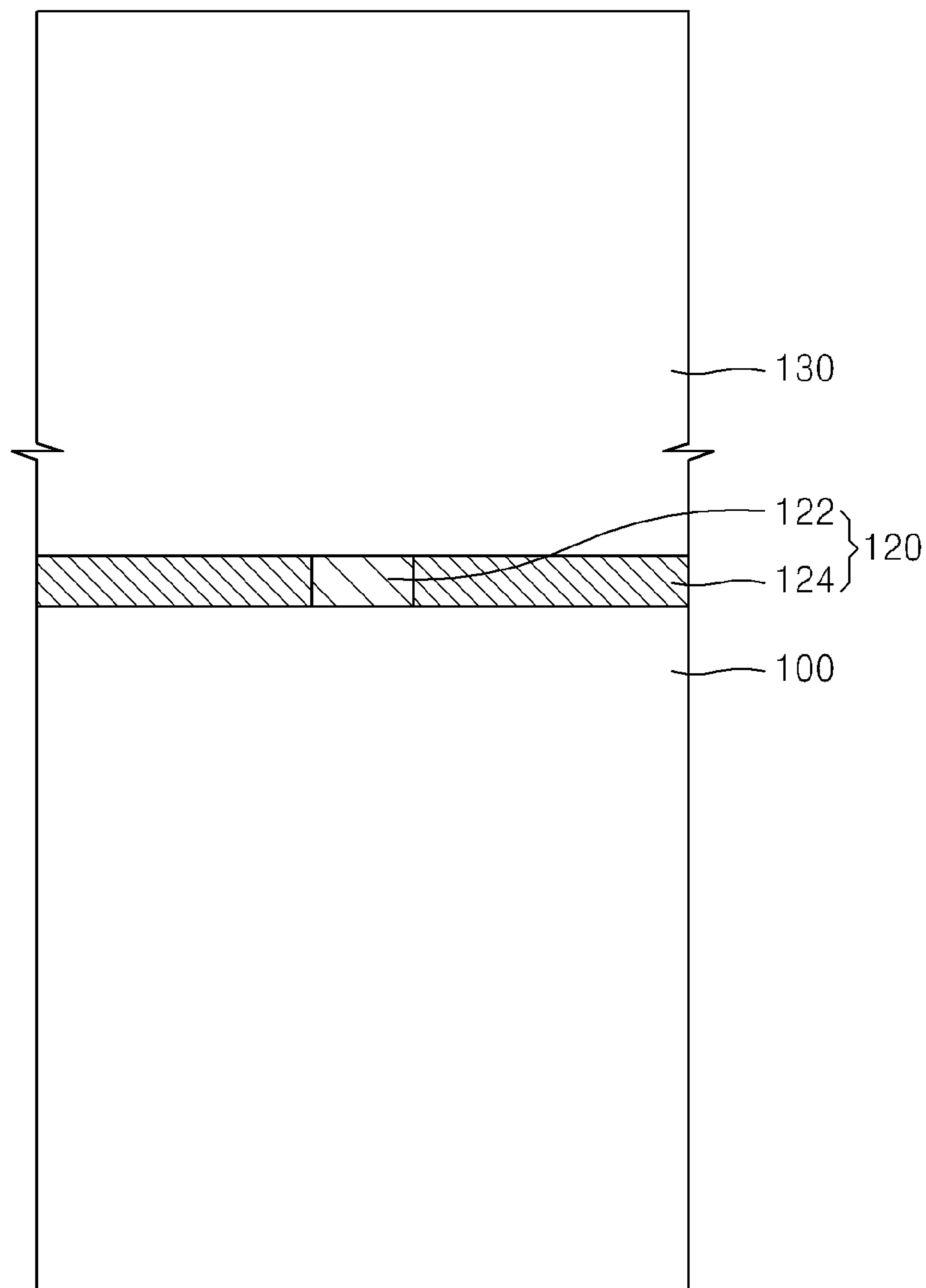


FIG. 14

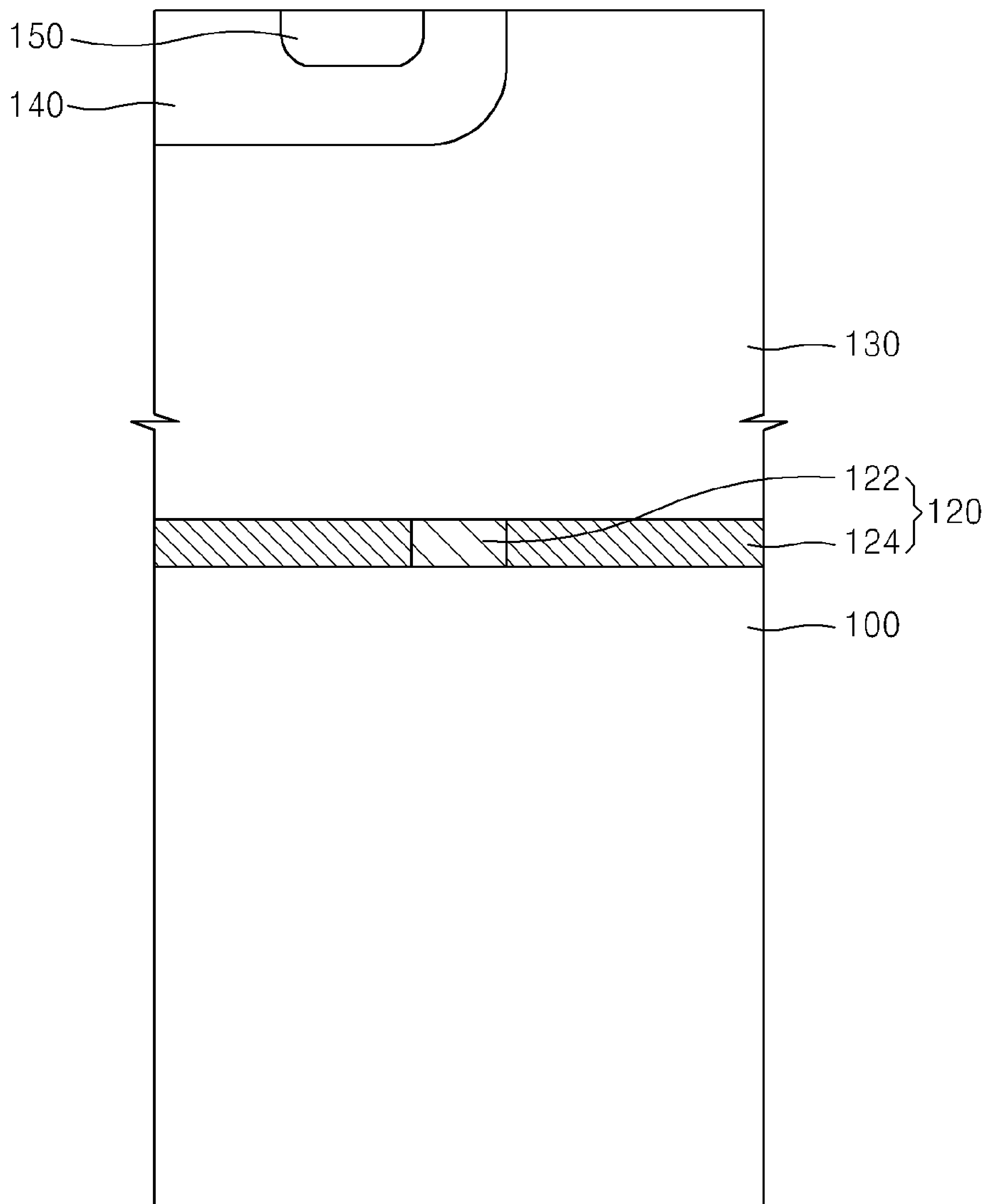


FIG. 15

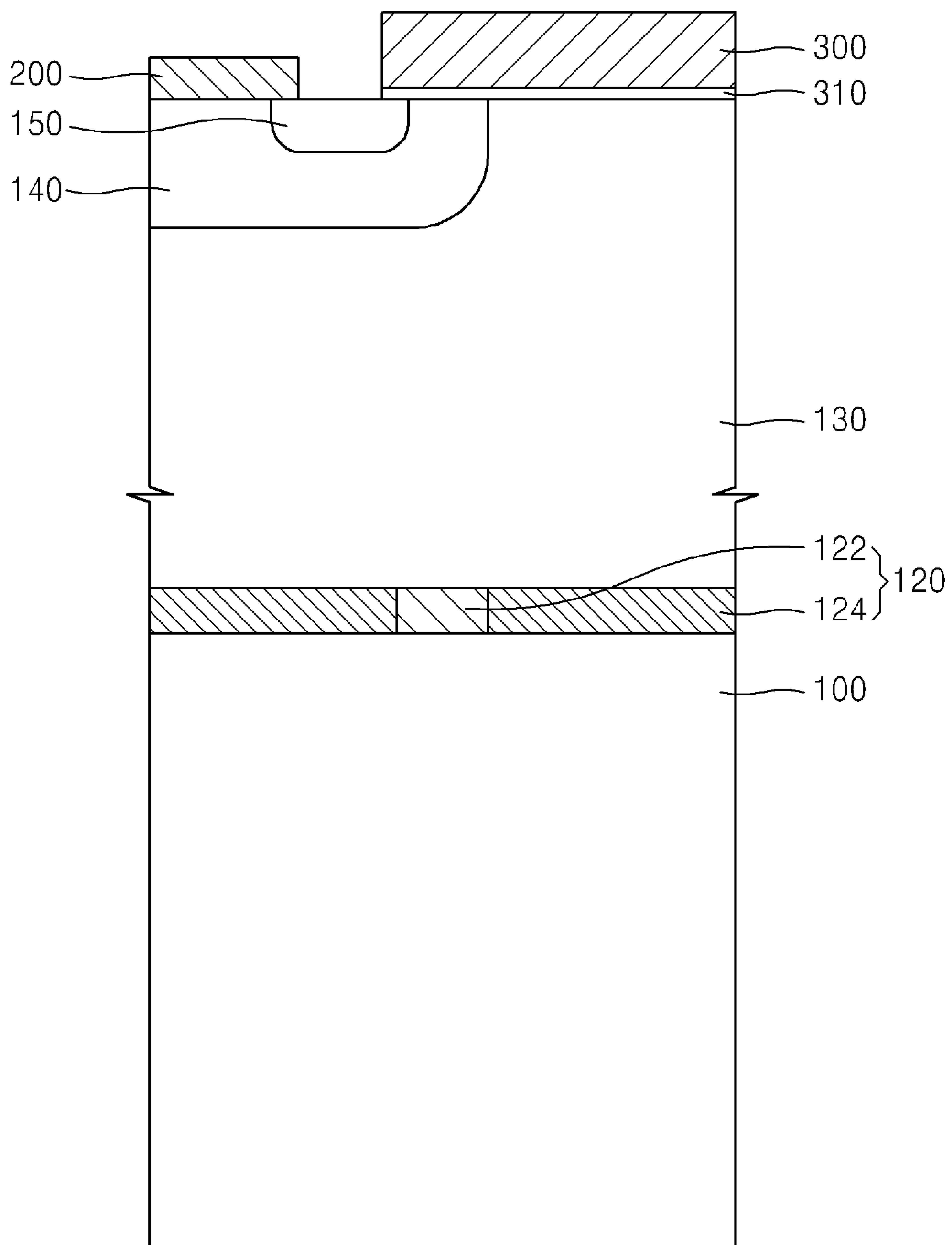


FIG. 16

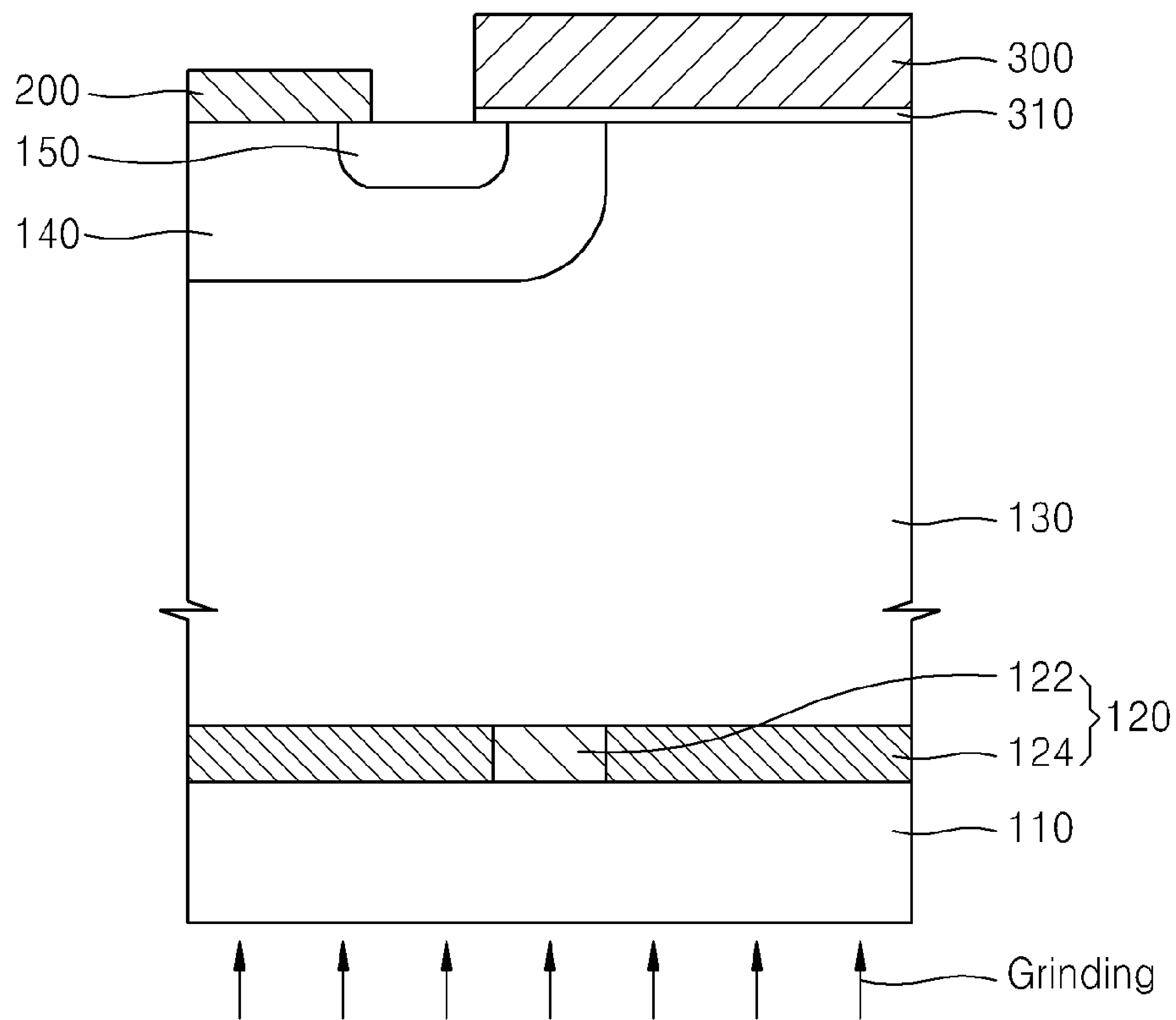


FIG. 17

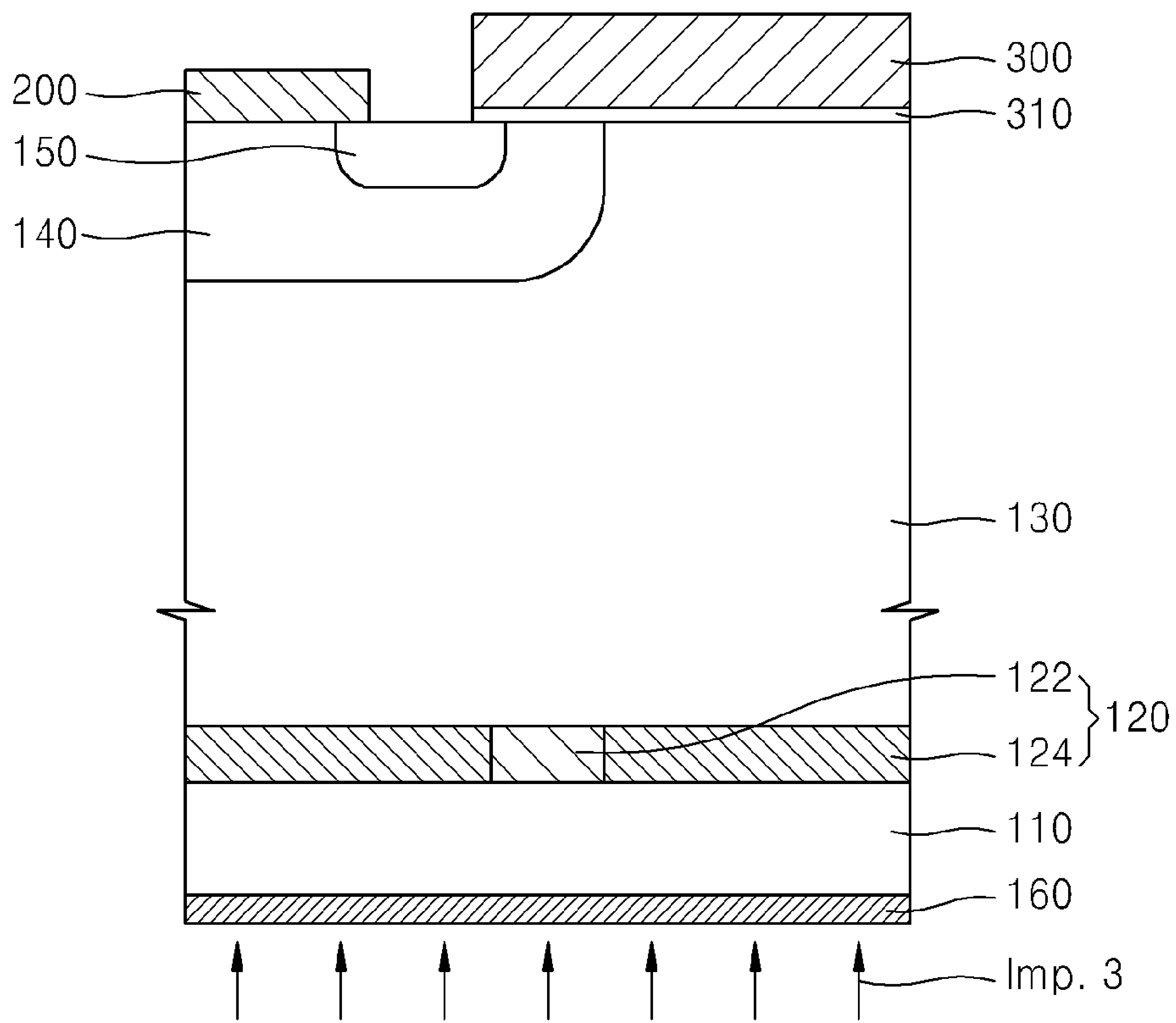


FIG. 18

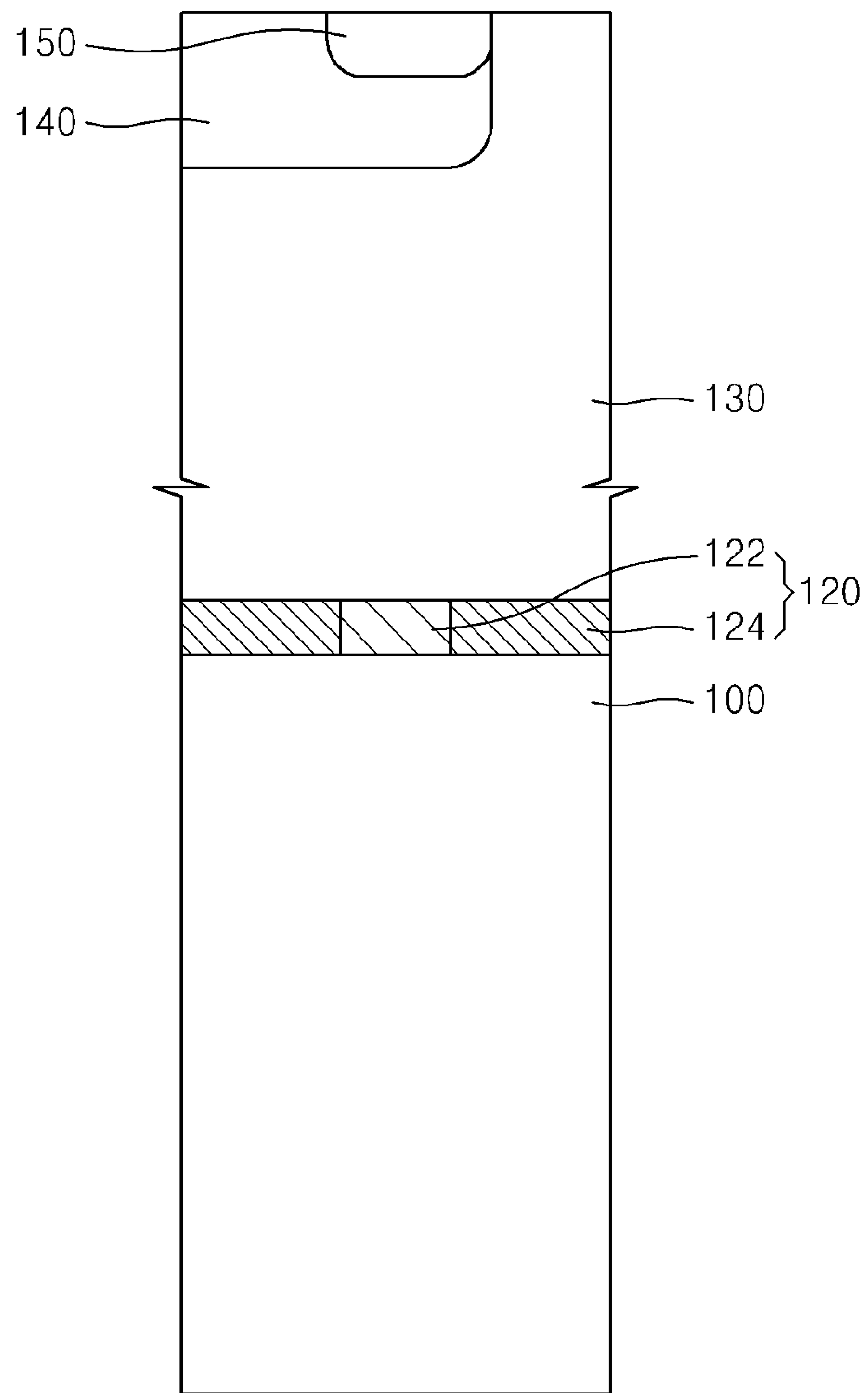


FIG. 19

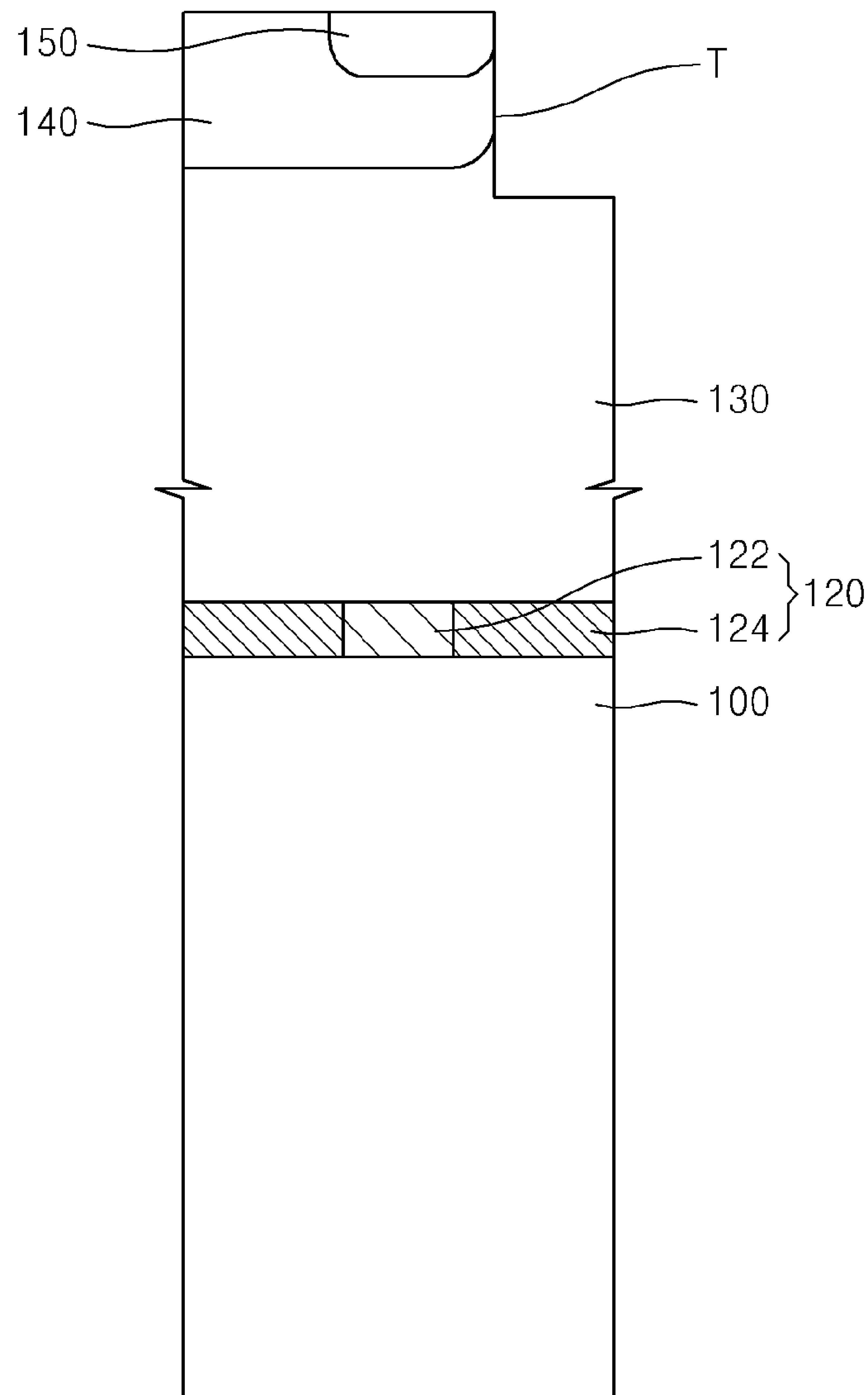


FIG. 20

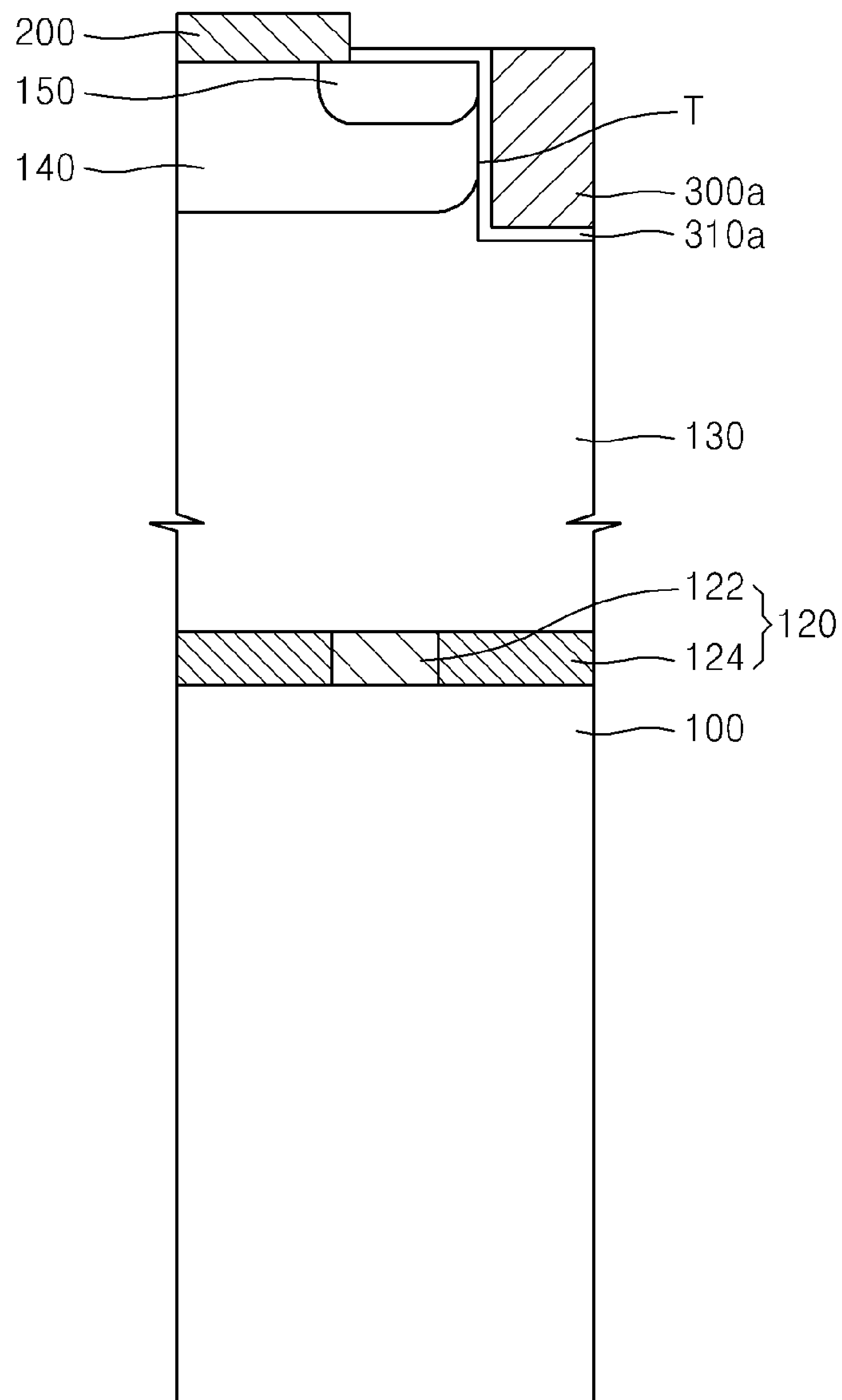


FIG. 21

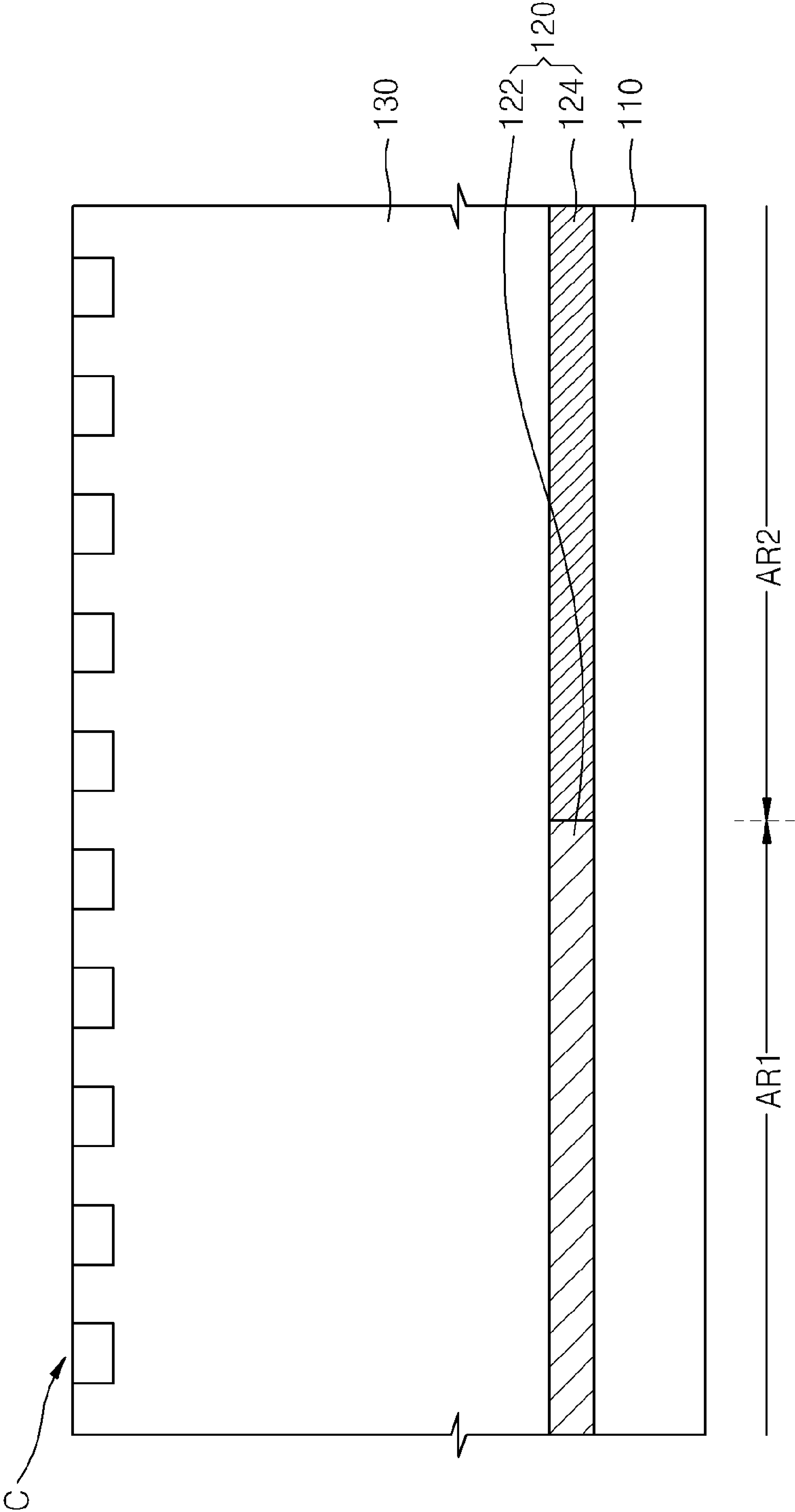


FIG. 22

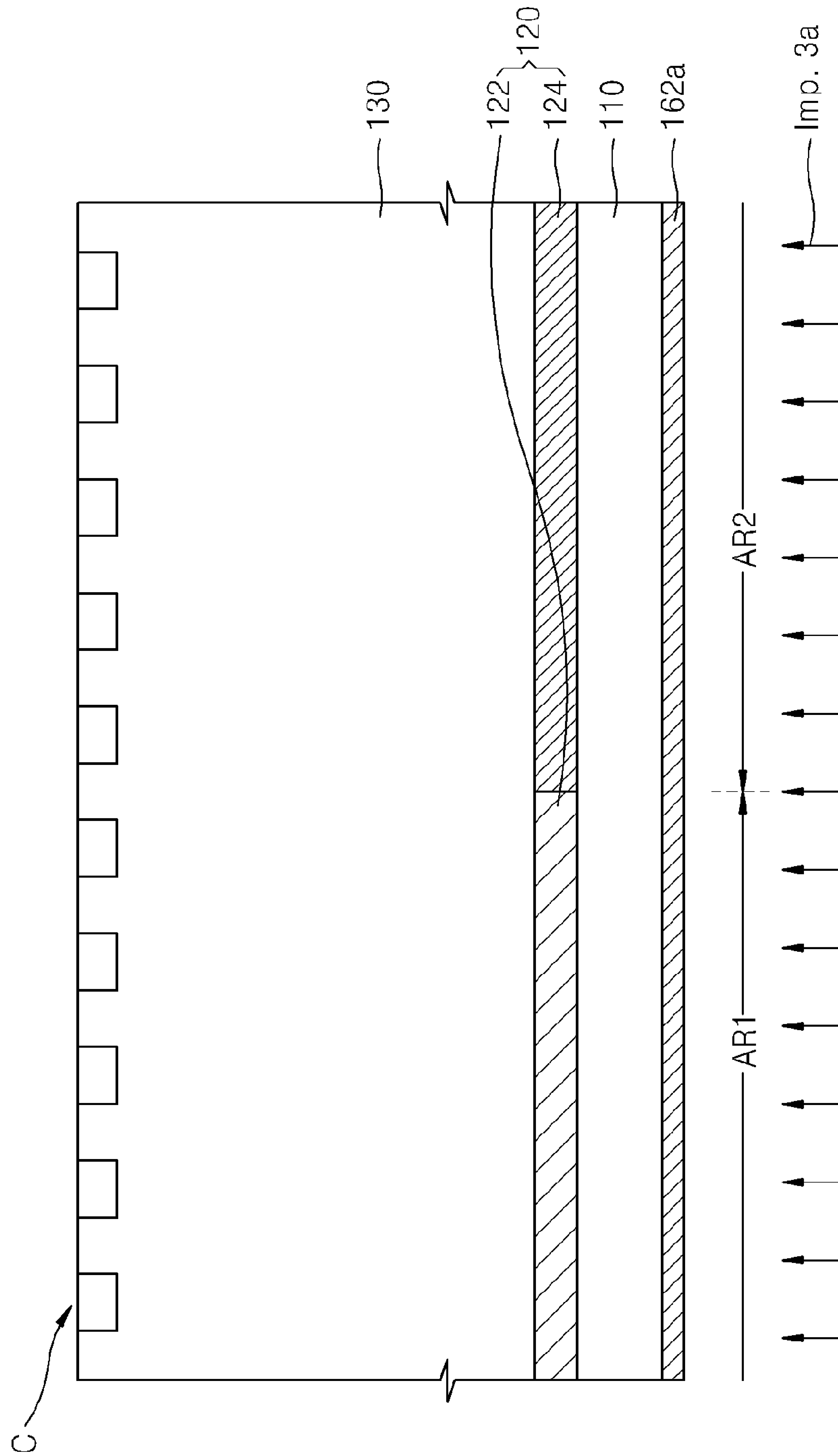
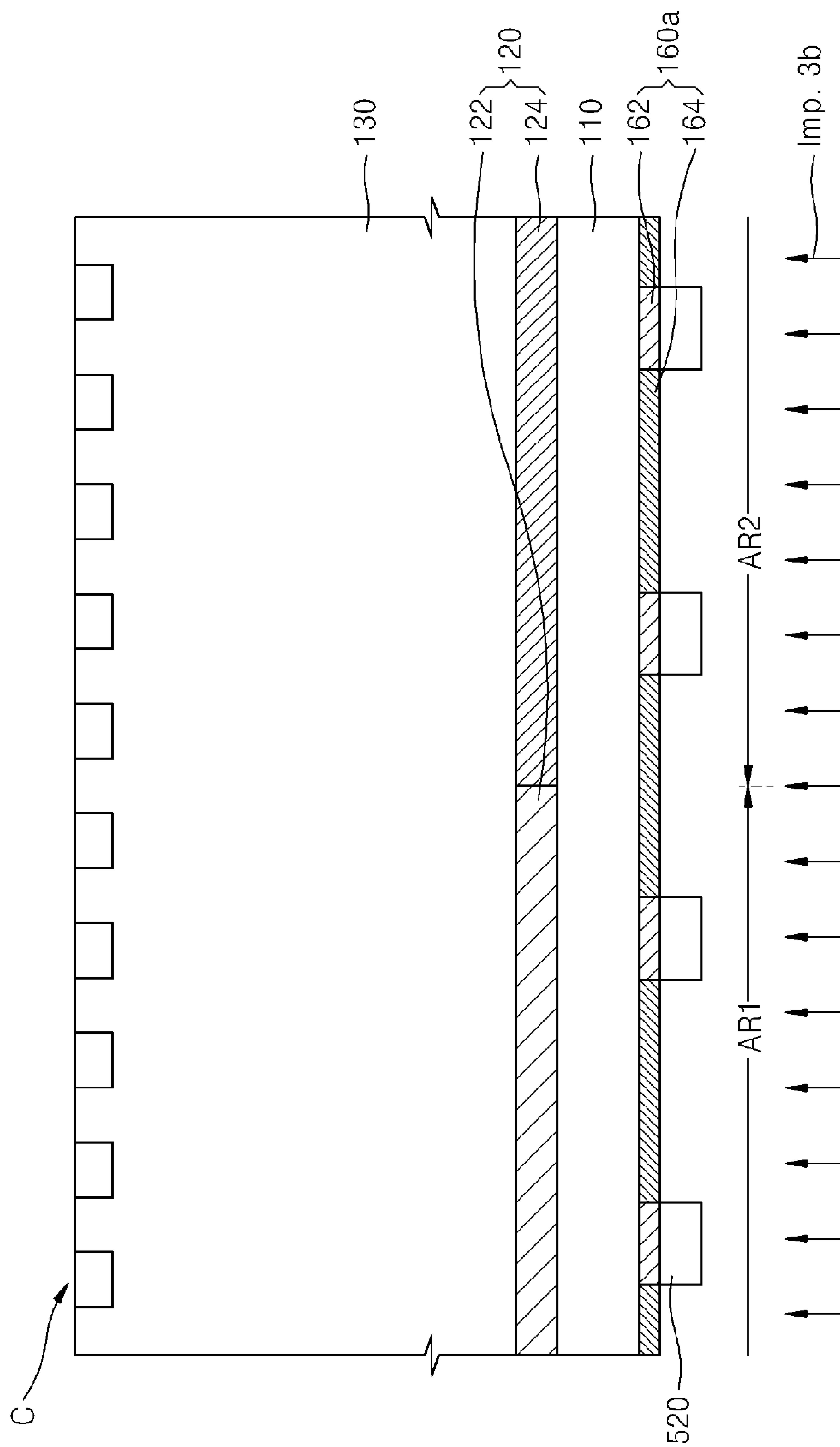


FIG. 23



POWER DEVICE AND METHOD OF MANUFACTURING THE SAME

RELATED APPLICATIONS

This application is a divisional application of U.S. application Ser. No. 14/316,248, filed Jun. 26, 2014, which claims the benefit of and priority to U.S. Provisional Application No. 61/840,444, filed on Jun. 27, 2013, in the U.S. Patent and Trademark Office, and claims priority to and the benefit of Korean Patent Application No. 10-2013-0161778, filed on Dec. 23, 2013 in the Korean Intellectual Property Office, the disclosures of which are incorporated herein in their entirety by reference.

Parent U.S. application Ser. No. 14/316,248 is also a U.S. Continuation-In-Part of U.S. patent application Ser. No. 13/868,629, filed on Apr. 23, 2013, which claims priority to and the benefit of Korean Patent Application No. 10-2012-0042717 filed on Apr. 24, 2012 in the Korean Intellectual Property Office, and claims priority to and the benefit of No. 10-2013-0043817 filed on Apr. 19, 2013 in the Korean Intellectual Property Office, the disclosures of which are incorporated herein in their entirety by reference

TECHNICAL FIELD

One or more embodiments relate to a power device and a method of manufacturing the same, and more particularly, to a power device and a method of manufacturing the same, wherein a semiconductor substrate is used as a field stop layer and a drift region is formed by growing an epitaxial layer on the semiconductor substrate.

BACKGROUND

1. Description of the Related Art

An insulated gate bipolar transistor (IGBT) has recently received attention as a power semiconductor device having both a high speed switching characteristic of a high power metal-oxide semiconductor field effect transistor (MOSFET) and a high power characteristic of a bipolar junction transistor (BJT). Among various types of IGBT structures, an IGBT of a Field Stop (FS) type may be understood as an IGBT of a soft punch-through type or a shallow punch-through type. Such an FS-IGBT may be understood as a combination of Non-Punch-Through (NPT) IGBT technology and PT IGBT technology, and accordingly, understood to have a low saturation collector-emitter voltage, favorable parallel operation, and ruggedness.

Nevertheless, a thinner and flatter wafer is required in manufacturing an FS-IGBT than manufacturing an NPT IGBT, and an n-type FS layer is required between a collector region and an N-drift region in order to prevent a depletion region from expanding with respect to the collector region.

SUMMARY

One or more embodiments include a power device and a method of manufacturing the same, wherein the power device, for example, a field stop-insulated gate bipolar transistor (FS-IGBT), includes an FS layer based on a semiconductor substrate between a collector region and a drift region, a thickness of the FS layer and an impurity concentration of the collector region can be adjusted, and functions of the FS layer are improved.

Additional aspects will be set forth in part in the description which follows and, in part, will be apparent from the description, or may be learned by practice of the presented embodiments.

According to one or more embodiments, there is provided a power device including a first field stop layer of a first conductive type and a second field stop layer formed on the first field stop layer and of the first conductive type where the second field stop layer has a region with an impurity concentration higher than the first field stop layer. The power device includes a drift region formed on the second field stop layer and of the first conductive type where the drift region has an impurity concentration lower than the first field stop layer and a plurality of power device cells formed on the drift region. The power device including a collector region formed below the first field stop layer where the second field stop layer includes a first region having a first impurity concentration and a second region having a second impurity concentration higher than the first impurity concentration.

The first region and the second region may contact each other.

The second impurity concentration may be at a depth higher than the first impurity concentration at the same depth.

An average impurity concentration of the second region may be higher than that of the first region.

The first region and the second region may be alternately disposed along a horizontal direction.

The second region may surround the first region at a same level.

The plurality of power device cells may be formed on the first region.

The power device may further include an edge termination structure on the drift region and on the second region where the edge termination structure surrounds the plurality of power device cells.

The collector region may be of a second conductive type that is different from the first conductive type.

The collector region includes a first collector region of the first conductive type and a second collector region of a second conductive type that is different from the first conductive type.

Some of the plurality of power device cells may be formed on the first region and a remainder of the plurality of power device cells may be formed on the second region.

The second field stop layer has an impurity concentration that increases from the first field stop layer to reach a maximum impurity concentration and then may decrease towards the drift region.

The first field stop layer and the drift region each may have a uniform impurity concentration profile in a depth direction.

The first field stop layer may be formed by grinding a rear surface of a Czochralski (CZ) single crystal substrate.

The drift region may be formed on the second field stop layer via an epitaxial growth.

The second field stop layer may be formed with a higher impurity concentration than the first field stop layer via an ion implant process.

The second field stop layer may be formed with the first impurity concentration via a first ion implant process, and the second region may be formed with the second impurity concentration via a second ion implant process.

Each of the plurality of power device cells may include: a base region disposed on the drift region and of a second conductive type that is different from the first conductive type; an emitter region disposed on a surface portion in the

base region and of the first conductive type; and a gate electrode formed adjacent the drift region, the base region, and the emitter region such that a gate insulating layer is disposed between the gate electrode and each of the drift region, the base region, and the emitter region.

Each of the plurality of power device cells may include: a base region disposed on the drift region and of a second conductive type different from the first conductive type; an emitter region disposed on a surface portion in the base region and of the first conductive type; a gate electrode disposed at one of a plurality of side surfaces of the base region and the emitter region, and embedded in the drift region; and a gate insulating layer disposed between the gate electrode and each of the base region, the emitter region, and the drift region.

According to one or more embodiments, there is provided a method of manufacturing a power device where the method includes preparing a semiconductor substrate of a first conductive type, performing a first ion implant process by implanting impurity ions of the first conductive type into a front surface of the semiconductor substrate to form an implanted field stop layer, and performing a second ion implant process by implanting impurity ions of the first conductive type into a part of the implanted field stop layer such that an impurity concentration of the part of the implanted field stop layer is higher than that of a remaining part of the implanted field stop layer. The method includes forming a drift region by growing an epitaxial layer having an impurity concentration that is lower than the semiconductor substrate on the implanted field stop layer and forming a plurality of power device cells on the drift region. The method also includes forming a field stop layer by grinding a rear surface opposite to the front surface of the semiconductor substrate, and forming a collector region below the field stop layer.

The performing of the second ion implant process may include: forming a first photoresist layer covering a first region of the implanted field stop layer; implanting impurity ions of the first conductive type into a second region of the implanted field stop layer exposed by the first photoresist layer, by using the first photoresist layer as a mask; and removing the first photoresist layer.

The forming of the plurality of power device cells may include forming the plurality of power device cells on the first region of the implanted field stop layer.

The second region may surround the first region at a constant depth, and the method may further include forming an edge termination structure on the drift region and on the second region to surround the plurality of power device cells.

The forming of the plurality of power device cells may include: forming a base region of a second conductive type that is different from the first conductive type on a surface region of the drift region; forming an emitter region of the first conductive type on a surface region of the base region; forming a gate electrode adjacent the drift region, the base region, and the emitter region such that a gate insulating layer is disposed between the gate electrode and each of the drift region, the base region, and the emitter region; and forming an emitter electrode on the base region and the emitter region.

The forming of the plurality of power device cells may include: forming a base region of a second conductive type different from the first conductive type on a surface region of the drift region; forming an emitter region of the first conductive type on a surface region of the base region; forming a trench adjacent to one of a plurality of side surfaces of the base region and the emitter region, and having an accommodation space therein by removing a portion of a surface of the drift region to a depth; forming a gate insulating layer covering an inner surface of the trench; forming a gate electrode in the trench where the gate insulating layer is formed; and forming an emitter electrode on the base region and the emitter region.

The forming of the collector region may include forming the collector region by implanting impurity ions of a second conductive type different from the first conductive type.

The forming of the collector region may include: performing a third ion implant process by implanting impurity ions of the first conductive type on the rear surface of the semiconductor substrate; and performing a fourth ion implant process by implanting impurity ions of a second conductive type different from the first conductive type into a part of the rear surface of the semiconductor substrate such that a part of the collector region is in a conductive type different from a remaining part of the collector region.

The performing of the fourth ion implant process may include: forming a second photoresist layer to cover a part of the rear surface of the semiconductor substrate; implanting impurity ions of the second conductive type into a remaining part of the rear surface of the semiconductor substrate exposed by the second photoresist layer, by using the second photoresist layer as a mask; and removing the second photoresist layer.

BRIEF DESCRIPTION OF THE DRAWINGS

These and/or other aspects will become apparent and more readily appreciated from the following description of the embodiments, taken in conjunction with the accompanying drawings in which:

FIG. **1** is a cross-sectional view of a field stop (FS) layer of a power device, according to an embodiment;

FIG. **2** is a cross-sectional view of an FS layer of a power device, according to another embodiment;

FIGS. **3**A and **3**B are plan views of a second FS layer of a power device, according to embodiments;

FIGS. **4**A through **4**C are graphs showing a doping concentration of an FS layer of a power device, according to embodiments;

FIGS. **5**A and **5**B are cross-sectional views of power device cells of a power devices, according to embodiments;

FIG. **6** is a cross-sectional view of power device cells of a power device, according to another embodiment;

FIGS. **7**A through **7**C respectively are a plan view and cross-sectional views of power device cells of power devices, according to other embodiments;

FIG. **8** is a cross-sectional view of power device cells of a power device, according to another embodiment;

FIGS. **9** through **17** are cross-sectional views for describing a method of manufacturing a power device, according to an embodiment;

FIGS. **18** through **20** are cross-sectional views for describing a method of manufacturing a power device, according to another embodiment; and

FIGS. **21** through **23** are cross-sectional views for describing a method of manufacturing a power device, according to another embodiment.

DETAILED DESCRIPTION

As the invention allows for various changes and numerous embodiments, exemplary embodiments will be illustrated in the drawings and described in detail in the written

description. However, this is not intended to limit the present invention to particular modes of practice, and it will to be appreciated that all changes, equivalents, and substitutes that do not depart from the spirit and technical scope of the present invention are encompassed in the present invention. In the drawings, like reference numerals denote like elements, and the sizes and thicknesses of layers and regions may be exaggerated for clarity.

It will also be understood that when an element is referred to as being "on" another element, it can be directly on the other element, or an intervening element may also be present. On the other hand, when an element is referred to as being "directly on" another element, it may be understood that an intervening element does not exist. Other expressions describing a relationship between elements, such as "between" and "directly between" may be interpreted in the same manner.

While such terms as "first", "second", etc., may be used to describe various elements, such elements must not be limited to the above terms. The above terms are used only to distinguish one element from another. For example, a first element may be referred to as a second element and similarly, a second element may be referred to as a first element without departing from the scope of the present invention.

An expression used in the singular encompasses the expression of the plural, unless it has a clearly different meaning in the context. In the present specification, it is to be understood that the terms such as "including" or "having," etc., are intended to indicate the existence of the features, numbers, steps, actions, components, parts, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other features, numbers, steps, actions, components, parts, or combinations thereof may exist or may be added.

As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this invention belongs.

Hereinafter, one or more embodiments of the present invention will be described in detail with reference to accompanying drawings.

FIG. **1** is a cross-sectional view of a field stop (FS) layer of a power device **1***a*, according to an embodiment.

Referring to FIG. **1**, the power device **1***a* includes a first FS layer **110**, a second FS layer **120**, and a drift region **130**. A power device cell may be formed on (or within) the drift region **130** of the power device **1***a*, and a collector region may be formed below the first FS layer **110**. The power device cell and the collector region will be described in detail later with reference to FIG. **5**A.

The first FS layer **110** may be formed based on a semiconductor substrate (not shown). For example, the first FS layer **110** may be formed by using a semiconductor substrate of a first conductive type. Here, the semiconductor substrate may be an impurity-doped substrate having a sufficient impurity concentration to form an FS layer in a field stop-insulated gate bipolar transistor (FS-IGBT), i.e., a sufficient impurity concentration to prevent a depletion region from expanding to the collector region of a second conductive type formed on a surface opposite a surface of the semiconductor substrate facing the drift region **130**. The impurity concentration of the semiconductor substrate for forming the first FS layer **110** may be from about $1E14/cm^3$ to about $1E16/cm^3$. For example, the first conductive type may be an N-type, the second conductive type may be a P-type, and the semiconductor substrate for forming the first FS layer **110** may be an N-type impurity doped N^0 semiconductor substrate.

The first FS layer **110** based on the semiconductor substrate as such may have an almost uniform impurity concentration profile in a height (or depth) direction (z-direction). In other words, the first FS layer **110** may have an overall constant impurity concentration.

Also, the semiconductor substrate forming the first FS layer **110** may be a single crystal substrate generated according to a Czochralski (CZ) technique that is widely and generally used to manufacture a large diameter wafer. Since a semiconductor substrate manufactured via a CZ technique is economical compared to a substrate manufactured via a float zone (FZ) technique, the semiconductor substrate may be used to realize an economical power device.

The second FS layer **120** may be formed by implanting impurity ions of the first conductive type in the first FS layer **110**. In detail, the second FS layer **120** may be formed by implanting the impurity ions of the first conductive type on an upper region of the semiconductor substrate of the first conductive type, and then activating the impurity ions via a thermal process. In the second FS layer **120**, an impurity concentration may gradually increase (along the z-direction) from an impurity concentration of the first FS layer **110** to a maximum impurity concentration, and then gradually decrease (along the z-direction) from the maximum impurity concentration to an impurity concentration of the drift region **130** on the second FS layer **120**. For example, the maximum impurity concentration of the second FS layer **120** may be from about $1E15/cm^3$ to about $2E17/cm^3$. However, the maximum impurity concentration of the second FS layer **120** is not limited thereto. Here, an impurity concentration is a concentration of impurities generated by activated impurity ions, and may be substantially the same as an impurity concentration injected during an ion implant process.

Since the first FS layer **110** is formed based on a semiconductor substrate and the second FS layer **120** is formed via an ion implant process, the first and second FS layers **110** and **120** may be respectively referred to as an FS layer and an implanted FS layer. The second FS layer **120**, together with the first FS layer **110**, may prevent a depletion region from expanding.

A thickness of the first FS layer **110** may decrease due to the existence of the second FS layer **120**. In other words, when an FS layer is realized by only using a semiconductor substrate without using an ion implant process, a collector region is formed at an opposite side of the semiconductor substrate, and thus, increasing an impurity concentration of the FS layer is limited and the FS layer may be relatively thick. However, in the power device **1***a* of the current embodiment, since the second FS layer **120** is separately formed via the ion implant process, increasing an impurity concentration of the FS layer may not be limited. Accordingly, a thickness of the first FS layer **110** may be sufficiently decreased, and as a result, a sum of the thicknesses of the first and second FS layers **110** and **120** may be lower than a thickness of an FS layer formed based on a semiconductor substrate without using an ion implant process. For example, the thickness of the FS layer formed based on the semiconductor substrate without using the ion implant process is equal to or higher than 10 μm, but in the power device **1***a* of the current embodiment, the thickness of the first FS layer **110** is about several μm and the thickness of the second FS layer **120** is also about several μm. Thus, the sum of the thicknesses of the first and second FS layers **110** and **120** may be lower than 10 μm.

The second FS layer **120** may operate as a barrier for preventing holes from being transmitted from the collector region to the drift region **130**.

The second FS layer **120** may include a first region **122** and a second region **124**. A part of the second FS layer **120** may be the first region **122**, and a remaining part of the second FS layer **120**, excluding the first region **122**, may be the second region **124**. The first and second regions **122** and **124** of the second FS layer **120** may contact each other. In other words, the first and second regions **122** and **124** of the second FS layer **120** may form a high-low junction.

The second region **124** may have a higher impurity concentration than the first region **122**. The second region **124** may have a higher impurity concentration than the first region **122** at the same level, i.e., at the same level (or substantially same level) in the height or depth direction (z-direction). The same level can be along approximately a same or uniform horizontal line or plane (e.g., along a same top surface, along a same middle region) along the height or depth direction. The first region **122** may have a first impurity concentration, and the second region **124** may have a second impurity concentration that is higher than the first impurity concentration.

The second FS layer **120** may be formed to have the first impurity concentration by implanting impurity ions of the first conductive type via a first ion implant process, and the second region **124** of the second FS layer **120** may be formed to have the second impurity concentration by additionally implanting impurity ions of the first conductive type via a second ion implant process. Accordingly, an average impurity concentration of the second region **124** may be higher than that of the first region **122**.

The second region **124** may be capable of high speed switching since a current tail of holes may be decreased while the power device **1***a* performs turn off switching.

A region of the second FS layer **120**, where the first region **122** is formed, may be referred to as a low concentration region L and a region of the second FS layer, where the second region **124** is formed, may be referred to as a high concentration region H. Accordingly, a region of the power device **1***a* where injecting of holes need to be decreased may be the high concentration region H, and a remaining region may be the low concentration region L, thereby adjusting an amount of holes being injected according to regions.

The first and second regions **122** and **124** may each include a higher impurity concentration region than the first FS layer **110**. The impurity concentrations of the first and second regions **122** and **124** may change in a depth direction (z-direction).

The drift region **130** may be formed by growing an epitaxial layer of the first conductive type on the second FS layer **120**. The drift region **130** may be formed to have a lower impurity concentration than the first FS layer **110**. In detail, the drift region **130** may be formed by growing the epitaxial layer of the first conductive type having a suitable impurity concentration for a breakdown voltage of the power device **1***a* of the first conductive type, on the second FS layer **120**. For example, the drift region **130** may have a lower relatively low impurity concentration than or equal to 1E14/cm^3. A thickness of the drift region **130** may vary according to a breakdown voltage required by an FS-IGBT. For example, when a breakdown voltage of the FS-IGBT is required to be about 600 V, the thickness of the drift region **130** may be about 60 μm. The drift region **130** may have a lower impurity concentration than the first FS layer **110**.

As described above, the impurity concentration of the second FS layer **120** may gradually increase (along the z-direction) from the impurity concentration of the first FS layer **110** to a maximum impurity concentration, and then gradually decrease (along the z-direction) from the maximum impurity concentration to the impurity concentration of the drift region **130**. When the drift region **130** has a lower impurity concentration than the first FS layer **110**, an impurity concentration of a part of the second FS layer **120** may be lower than the impurity concentration of the first FS layer **110**. In other words, the second FS layer **120** may include a region adjacent to the first FS layer **110** that has a higher impurity concentration than the first FS layer **110**, and a region adjacent to the drift region **130** that has a lower impurity concentration than the first FS layer **110**.

When the drift region **130** is epitaxially grown, a concentration of doped impurities may vary. Accordingly, an impurity concentration profile of the drift region **130** in the depth direction (z-direction) may be constant or may change. In other words, when the drift region **130** is epitaxially grown, the impurity concentration profile of the drift region **130** may change by adjusting a type of the doped impurities, an amount of impurity ions, and/or a diffusion time of the impurity ions. In the power device **1***a* of the current embodiment, the impurity concentration profile of the drift region **130** may be uniform along the depth direction thereof. Profiles of impurity concentrations of the first FS layer **110**, the first and second regions **122** and **124** of the second FS layer **120**, and the drift region **130** may be as shown in FIGS. **4**A through **4**C.

FIG. **2** is a cross-sectional view of an FS layer of a power device **1***b*, according to another embodiment. While describing FIG. **2**, repeated descriptions with reference to FIG. **1** are omitted.

Referring to FIG. **2**, the power device **1***b* includes the first FS layer **110**, the second FS layer **120**, and the drift region **130**. A power device cell may be formed on the drift region **130**, and a collector region may be formed below the first FS layer **110**.

The second FS layer **120** may include the first region **122** and the second region **124**. The first and second regions **122** and **124** may be alternately disposed along a horizontal direction (for example, an x-direction) perpendicular to the height direction (z-direction). The second region **124** may surround (e.g., may have different portions disposed on each side of, may have a portion disposed entirely around) the first region **122** at the same level in the depth direction (z-direction).

In the power device **1***a* of FIG. **1**, the second region **124** of the second FS layer **120** is disposed in a region where injecting of holes may be reduced, and the first region **122** is the remaining region of the second FS layer **120**. In the power device **1***b* of FIG. **2**, the second region **124** may be formed to surround (e.g., may have different portions disposed on each side of, may have a portion disposed entirely around) the first region **122** such that holes are injected mainly through the first region **122**.

Examples of arrangements of the first and second regions **122** and **124** of the second FS layer **120** of the power device **1***b* are shown in FIGS. **3**A and **3**B.

FIGS. **3**A and **3**B are plan views of the second FS layer **120** of the power device **1***b*, according to embodiments of the present invention. In detail, FIGS. **3**A and **3**B are cross-sectional views taken long line III-III of FIG. **2**.

Referring to FIG. **3**A, the first region **122** may have a line shape extending along one direction (y-direction). Also, the second regions **124** between the first regions **122** may have a line shape extending along the one direction (y-direction). The first and second regions **122** and **124** may be alternately

disposed along the horizontal direction (for example, the x-direction). The first and second regions **122** and **124** may be alternately disposed along a horizontal direction (for example, the x-direction) perpendicular to an extending direction (y-direction).

Referring to FIG. **3**B, the second region **124** may be formed to completely surround the first region **122**. The first region **122** may be a remaining part of the second FS layer **120** that is limited by the second region **124**. The plurality of first regions **122** may be disposed in an array having a matrix form along perpendicular directions (x- and y-directions).

An amount of holes transmitted to the drift region **130** may be adjusted in the power device **1***b* of FIG. **2** by adjusting a ratio of areas of the first and second regions **122** and **124**.

Also, a shape of the first region **122** may be selected based on a shape of a power device cell to be formed. For example, when the power device cell to be formed has a line shape extending along one direction (y-direction), the first region **122** may have a line shape extending along the one direction (y-direction), as shown in FIG. **3**A. For example, when a plurality of power device cells are formed as an array having a matrix form, the first regions **122** may be formed as an array having a matrix form as shown in FIG. **3**B.

However, the shape of the first region **122** is not limited to a shape similar to a shape of the power device cell to be formed, and may have any shape by considering an amount of holes to be injected.

FIGS. **4**A through **4**C are graphs showing a doping concentration of the power device **1***b*, according to embodiments of the present invention. In detail, FIG. **4**A is a graph showing a doping concentration along line IVa-IVa of FIG. **3**A, and FIGS. **4**B and **4**C are graphs respectively showing doping concentrations along lines IVb-IVb and IVc-IVc of FIG. **2**.

Referring to FIG. **4**A, an impurity concentration profile of the second FS layer **120** of FIG. **3**A is shown across the low concentration region L and the high concentration region H, i.e., the first and second regions **122** and **124**. A first impurity concentration D**1** of the first region **122** may be lower than a second impurity concentration D**2** of the second region **124**. The first and second impurity concentrations D**1** and D**2** each have a constant value at the same level, but there may be a section where an impurity concentration changes from the second impurity concentration D**1** to the first impurity concentration D**1** due to diffusion on a boundary of the first and second regions **122** and **124**.

Referring to FIG. **4**B, an impurity concentration profile of the low concentration region L of the power device **1***b* of FIG. **2** is shown in the depth direction (z-direction). The drift region **130** may have a fourth impurity concentration D**4** that is constant along the depth direction (z-direction). Alternatively, as described above, the forth impurity concentration D**4** of the drift region **130** may change according to depth.

The impurity concentration of the first region **122** gradually increases from a region contacting the drift region **130** to a maximum impurity concentration region A to reach the first impurity concentration D**1**, and then gradually decreases to reach a third impurity concentration D**3** of the first FS layer **110**.

The first FS layer **110** based on the semiconductor substrate may have the third impurity concentration D**3** that is constant according to depth.

Referring to FIG. **4**C, an impurity concentration profile of the high concentration region H of the power device **1***b* of FIG. **2** is shown in the depth direction (z-direction). The tendency of the impurity concentration profile of the high concentration region H in the depth direction (z-direction) is almost similar to the impurity concentration profile of the low concentration region L of FIG. **4**B in the depth direction (z-direction).

The impurity concentration of the second region **124** gradually increases from a region contacting the drift region **130** to a maximum impurity concentration region B to reach the second impurity concentration D**2** that is higher than the first impurity concentration D**1**, and then gradually decreases to reach the third impurity concentration D**3** of the first FS layer **110**.

FIG. **5**A is a cross-sectional view of a power device cell C**1** of a power device **1000***a*, according to an embodiment of the present invention.

Referring to FIG. **5**A, the power device **1000***a* includes the first FS layer **110**, the second FS layer **120**, the drift region **130**, a base region **140**, an emitter region **150**, and a collector region **160**. Descriptions about the first FS layer **110**, the second FS layer **120**, and the drift region **130** above with reference to FIGS. **1** through **4**C are omitted here.

The base region **140** and the emitter region **150** may be formed as regions above or on the drift region **130** (e.g., an upper surface of the drift region **130**). For example, the base region **140** may be formed by selectively implanting impurity ions of the second conductive type in the upper surface of the drift region **130**, and diffusing and/or activating the impurity ions via a thermal process. The base region **140** may be, for example, a high concentration P-type (P+) impurity region. The base region **140** may form a P-N junction region with the drift region **130**. The base region **140** may include a first base region P++ (not shown) at an upper portion of the base region **140** and a second base region P− (not shown) formed below the first base region P++ according to concentrations. For example, the first base region P++ may have an impurity concentration of 1E19/cm^3, and the second base region P− may have an impurity concentration of about 1E17 cm^3.

The emitter region **150** may be formed by selectively implanting impurity ions of the first conductive type on a certain upper surface region in the base region **140**, and diffusing and/or activating the impurity ions via a thermal process. The emitter region **150** may be, for example, a high concentration N-type (N+) impurity region. For example, the emitter region **150** may have an impurity concentration from about 1E18/cm^3 to about 1E20/cm^3.

An emitter electrode **200** may be formed throughout the base region **140** and the emitter region **150**. Also, a gate electrode **300** may be formed on the drift region **130**, the base region **140**, and the emitter region **150** across a gate insulating layer **310**. Accordingly, the gate insulating layer **310** is disposed between the gate electrode **300** and each of the drift region **130**, the base region **140**, and the emitter region **150**. The gate electrode **300** may set a channel in the base region **140** between the drift region **130** and the emitter region **150** by applying a voltage to the gate electrode **300**.

Although not illustrated, an insulating layer and/or passivation layer covering the emitter electrode **200** and the gate electrode **300** may be formed.

The collector region **160** may be formed below the first FS layer **110**. In other words, the collector region **160** may be formed by grinding a rear surface of the semiconductor substrate, implanting impurity ions of the second conductive type into the rear surface of the semiconductor substrate, and activating the impurity ions via a thermal process. The collector region **160** may have a relatively small thickness. For example, the collector region **160** may have a thickness

that is lower than or equal to 1 μm. For example, the collector region **160** may be a high concentration P-type (P+) impurity region. An impurity concentration of the collector region **160** may be higher than the impurity concentrations of the first and second FS layers **110** and **120**. A collector electrode **400** may be formed on a bottom surface of the collector region **160**.

When a plurality of the power device cells C**1** are formed, the collector region **160** may be used as a common region. Accordingly, a power device cell herein may designate a base region and an emitter region forming one IGBT as well.

Also, an N-type power device has been described above, but a P-type power device may also be manufactured by switching conductive types of impurities in corresponding regions.

In the power device **1000***a* of the current embodiment, the impurity concentration of the second FS layer **120** may be controlled by forming the second FS layer **120** by implanting impurity ions. Also, by elaborately adjusting the impurity concentration of the second FS layer **120**, the thickness or impurity concentration profile of the second FS layer **120** may be variously adjusted. Also, injecting of holes may be reduced by forming the second FS layer **120** to include the first region **122** having the first impurity concentration and the second region **124** having the second impurity concentration that is higher than the first impurity concentration. Accordingly, the power device **1000***a* may have a high speed switching characteristic by remarkably improving electric characteristics such as an on-off switching waveform.

Since the second FS layer **120** is formed separately from the first FS layer **110** based on the semiconductor substrate, the impurity concentration of the collector region **160** formed on the bottom surface of the first FS layer **110** may be easily adjusted. Also, in some implementations, since the first FS layer **110** is formed by grinding the rear surface of the semiconductor substrate, a high energy ion injection process for the first FS layer **110** and an accompanying annealing diffusion process are not required.

FIG. **5**B is a cross-sectional view of a power device cell C**2** of a power device **1000***b*, according to an embodiment of the present invention. In detail, the power device **1000***b* of FIG. **5**B is the same as the power device **1000***a* of FIG. **5**A, except for the base region **140**, the emitter region **150**, a gate electrode **300***a*, and a gate insulating layer **310***a*, and thus descriptions already provided above with reference to FIG. **5**A are omitted for convenience of description.

Referring to FIG. **5**B, the power device **1000***b* may have a trench-gate structure. A trench T having an accommodation space therein may be formed in the drift region **130** by removing portion of the drift region **130** to a predetermined depth. The gate insulating layer **310***a* is formed to cover an inner surface of the trench T.

Here, the trench T may be adjacent to one of the side surfaces of the base region **140** and emitter region **150**. The gate insulating layer **310***a* is formed to cover a part of the top surface of the emitter region **150**, but alternatively, the gate insulating layer **310***a* may not be formed on the top surface of the emitter region **150**.

The gate electrode **300***a* is formed in the accommodation space of the trench T where the gate insulating layer **310***a* is formed. Here, the top surface of the gate electrode **300***a* may form the same plane as the top surface of the drift region **130**, but an embodiment is not limited thereto. For example, the top surface of the gate electrode **300***a* may protrude further than the top surface of the drift region **130**.

As shown in FIG. **5**B, the base region **140** and the emitter region **150** may be disposed adjacent to one side wall of the trench T including the gate electrode **300***a* and the gate insulating layer **310***a*.

When a plurality of the power device cells C**2** are formed, the collector region **160** may be formed as one common region.

Unlike the gate electrode **300** of FIG. **5**A, the gate electrode **300***a* of FIG. **5**B is formed in the trench T, and thus an area of the gate electrode **300***a* may be reduced in the power device **1000***b*.

Referring to FIGS. **5**A and **5**B, the second region **124** of the second FS layer **120** may function as a barrier for preventing holes from being transmitted from the collector region **160** to the drift region **130**. In other words, hole injection H.I may be performed mainly through the first region **122** of the second FS layer **120**. Accordingly, the power device **1000***a* or **1000***b* may perform high speed switching since the second region **124** reduces a current tail of holes during turn off switching of the power device **1000***a* or **1000***b*.

FIG. **6** is a cross-sectional view of power device cells C of a power device **1000***c*, according to another embodiment of the present invention.

Referring to FIG. **6**, the power device **1000***c* may include the plurality of power device cells C. A power device cell C may be the power device cell C**1** or C**2** of FIG. **5**A or **5**B, but is not limited thereto. The power device cell C may include the drift region **130** and all elements formed thereon to form one IGBT.

In the power device **1000***a* or **1000***b* of FIG. **5**A or **5**B, the second region **124** may be formed to correspond to one power device cell C**1** or C**2**. The power device **1000***a* may further include an emitter electrode (not shown), a gate electrode (not shown), and a collector electrode (not shown). However, the power device **1000***c* of FIG. **6** may include the second region **124** regardless of arrangements of the power device cells C. In other words, when the power device **1000***c* includes the power device cells C, the second region **124** may be freely arranged to adjust an amount of holes injected from the collector region **160** to the drift region **130**. Hole injection H.I may be mainly performed through the first region **122** of the second FS layer **120**. Accordingly, the ratio of areas and arrangements of the first and second regions **122** and **124** may be selected to increase or reduce hole injection as required.

FIG. **7**A is a plan view of power device cells C of a power device **1000***d*, according to another embodiment of the present invention.

Referring to FIG. **7**A, the power device **1000***d* may include the plurality of power device cells C. The power device **1000***d* may be, for example, one power device die separated to form one power device package.

The power device **1000***d* may include an active region AR where the power device cells C are formed, and an edge termination region ER surrounding the active region AR. The edge termination region ER may have a ring shape surrounding the active region AR, and an edge termination structure described later may be formed throughout or on some of the edge termination region ER.

In FIG. **7**A, the plurality of power device cells C are arranged in an array having a matrix form along a vertical direction, but an arrangement of the power device cells C is not limited thereto.

FIG. **7**B is a cross-sectional view of power device cells C of a power device **1000***d*-**1**, according to another embodiment of the present invention. In detail, FIG. **7**B is a

cross-sectional view showing the power device cells C of the active region AR and the edge termination region ER of FIG. **7**A.

Referring to FIG. **7**B, the power device **1000***d***-1** may include the plurality of power device cells C. The power device **1000***d***-1** may further include an emitter electrode (not shown), a gate electrode (not shown), and a collector electrode (not shown). The power device cells C may be formed in the active region AR. An edge termination structure ET may be formed on an upper portion of the drift region **130** in the edge termination region ER. The edge termination structure ET may be disposed on the upper portion of the drift region **130** to surround the power device cells C, along the edge termination region ER surrounding the active region AR as shown in FIG. **7**A.

As described above with reference to FIG. **5**A, a P-N junction region between the drift region **130** and the power device cell C, which is formed by the drift region **130** and the base region **140**, does not continue throughout a wafer where a power device is formed. In other words, when one power device die is sawed to form one power device package, crowding of an electric field is generated at an end of the P-N junction region, and thus a breakdown voltage of the power device may be decreased. Accordingly, the edge termination structure ET may be formed along the edge of the power device die, i.e., to surround the plurality of power device cells C. The edge termination structure ET may have any shape, and descriptions about a detailed structure thereof are omitted here. For example, the edge termination structure ET may have a structure as disclosed in U.S. Pat. No. 7,872,300, U.S. Pat. No. 7,074,715, U.S. Pat. No. 825,873, and U.S. 2012-161274 (which are incorporated herein by reference in their entirety), but is not limited thereto.

Referring back to FIG. **7**B, the edge termination structure ET may be formed on the second region **124** of the second FS layer **120** in the power device **1000***d***-1**. Also, the plurality of power device cells C may be formed on the first region **122** of the second FS layer **120** in the power device **1000***d***-1**. In this case, hole injection H.I may mainly be performed towards the power device cells C through the first region **122**. Accordingly, crowding of an electric field described above may be reduced, and thus a breakdown voltage of the power device **1000***d***-1** is prevented from decreasing. Also, since the edge termination structure ET may be formed to occupy a relatively less area, more power device cells C may be formed in the power device **1000***d***-1** having the same area, and thus the power device **1000***d***-1** may have a higher driving current.

Also, selectively, the edge termination structure ET may cover the entire top surface of the second region **124** and may be formed on a part of the first region **122**, and the plurality of power device cells C may be disposed relatively in the first region **122**, so as to reduce the number of holes injected from a region of the first region **122** adjacent to the second region **124** to the edge termination structure ET.

In other words, the first region **122** is formed in the active region AR and the second region **124** is formed in the edge termination region ER in FIG. **7**B, but alternatively, a boundary of the active region AR and the edge termination region ER may be formed to be disposed inside the first region **122** from a boundary of the first and second regions **122** and **124**.

FIG. **7**C is a cross-sectional view of power device cells C of a power device **1000***d***-2**, according to another embodiment of the present invention. In detail, FIG. **7**C is a cross-sectional view showing the power device cells C of the active region AR and the edge termination structure ET of FIG. **7**A. Descriptions already provide above with reference to FIG. **7**B are omitted here.

Referring to FIG. **7**C, the power device **1000***d***-2** may include the plurality of power device cells C. The power device cells C may be formed in the active region AR. The edge termination structure ET may be formed on an upper portion of the drift region **130** in the edge termination region ER.

In the power device **1000***d***-2**, the first region **122** of the second FS layer **120** may be formed only on a part of the active region AR. In other words, the first and second regions **122** and **124** of the second FS layer **120** may be disposed such that the power device **1000***d***-2** of FIG. **7**C has characteristics of the power device **1000***c* of FIG. **6** and the power device **1000***d***-1** of FIG. **7**B. Accordingly, crowding of an electric field described above may be reduced, thereby preventing a breakdown voltage of the power device **1000***d***-2** from decreasing, and at the same time, hole injection H.I may be increased or decreased as required.

FIG. **8** is a cross-sectional view of power device cells C of a power device **1000***e*, according to another embodiment of the present invention.

Referring to FIG. **8**, the power device **1000***e* includes the plurality of power device cells C formed in a first active region AR**1** and a second active region AR**2**. A collector region **160***a* of the power device **1000***e* may include a first collector region **162** of the first conductive type, and a second collector region **164** of the second conductive type. The first collector region **162** may have a higher impurity concentration than the first FS layer **110**. The second collector region **164** may have a higher impurity concentration than the first collector region **162**.

Since the collector region **160***a* includes the first collector region **162** of the first conductive type and the second collector region **164** of the second conductive type, the power device cell C may operate as a shorted anode IGBT or a reverse conducting IGBT.

Here, when the first region **122** of the second FS layer **120** is formed in the first active region AR**1** and the second region **124** of the second FS layer **120** is formed in the second active region AR**2**, hole injection H.I in the first and second active regions AR**1** and AR**2** may be controlled. Accordingly, the power device cell C in the first active region AR**1** operates as a general IGBT and the power device cell C in the second active region AR**2** operates as a shorted anode IGBT or reverse conducting IGBT, and thus, the power device **1000***e* may realize a bi-mode IGBT.

The collector region **160***a* may be formed by performing an ion implant process on the rear surface of the semiconductor substrate. Accordingly, in order to classify the power device cell C operating as a general IGBT and the power device cell C operating as a shorted anode IGBT or reverse conducting IGBT based on the existence of the second collector region **164**, a precision of alignment during the ion implant process through the rear surface of the semiconductor substrate is important. However, since the power device cells C are formed towards the top surface of the semiconductor substrate, it is difficult to accurately classify and align the power device cells C during the ion implant process through the rear surface of the semiconductor substrate.

However, in the current embodiment, since the second FS layer **120** is formed via the ion implant process through the top surface of the semiconductor substrate, the second FS layer **120** may be easily aligned with the power device cells

C. Thus, a bi-mode IGBT may be easily realized without having to perform alignment through the rear surface of the semiconductor substrate.

Although the collector electrode **400** shown in FIG. **5**A or **5**B is not illustrated in FIGS. **7**B, **7**C, and **8**, the collector electrode **400** of FIG. **5**A or **5**B may be formed on bottom surfaces of the collector regions **160** and **160***a*. Similarly, the emitter electrode **200** and the gate electrode **300** or the gate insulating layer **300***a* of FIG. **5**A or **5**B may be formed on the power device cells C of FIGS. **7**B, **7**C, and **8**.

A method of manufacturing a power device, according to one or more embodiments of the present invention, will now be described. Methods of manufacturing the power devices **1000***a*, **1000***b*, and **1000***e* of FIGS. **5**A, **5**B, and **8** are described with reference to FIGS. **9** through **23**.

FIGS. **9** through **17** are cross-sectional views for describing a method of manufacturing a power device, according to an embodiment of the present invention. In detail, the method shown in FIGS. **9** through **17** is used to manufacture the power device **1000***a* of FIG. **5**A.

Referring to FIG. **9**, a semiconductor substrate **100** of the first conductive type is prepared. For example, the first conductive type may be an N-type, and in this case, an N-type impurity ion-doped N^0 semiconductor substrate may be prepared. Here, the semiconductor substrate **100** may be an N-type impurity ion-doped substrate having an impurity concentration required for an FS layer in an FS-IGBT, i.e., having an impurity concentration at a side of a sufficient P-type collector region to prevent a depletion region from being extended to the P-type collector region to be formed on a surface of the semiconductor substrate **100**. For example, the semiconductor substrate **100** may have an impurity concentration from about $1E14/cm^3$ to about $1E16/cm^3$. An impurity concentration profile of the semiconductor substrate **100** may be uniform in a depth direction of the semiconductor substrate **100**, as shown in the impurity concentration profile of the first FS layer **110** of FIGS. **4**B and **4**C.

The semiconductor substrate **100** may be a substrate manufactured according to a CZ technique that is generally used to manufacture a large diameter wafer. Also, the semiconductor substrate **100** may be manufactured via a float zone (FZ) technique.

Referring to FIG. **10**, an implant layer **122***a* is formed on an upper region of the semiconductor substrate **100** by performing a first ion implant process Imp.**1** for implanting impurity ions of the first conductive type. An impurity concentration of the implant layer **122***a* may vary according to a depth direction, and may be from about $1E15/cm^3$ to about $1E17/cm^3$. A thickness of the implant layer **122***a* may be about several μm. In some cases, the thickness of the implant layer **122***a* may be about dozens of μm.

Referring to FIG. **11**, a first photoresist layer **510** is formed on part of the implant layer **122***a* to cover part of the implant layer **122***a*. The first photoresist layer **510** may be formed via a photolithography process. The part of the implant layer **122***a* that is covered by the first photoresist layer **510** may be the first region **122** of FIG. **5**A.

Referring to FIG. **12**, the second region **124** is formed by performing a second ion implant process Imp.**2** for implanting impurity ions of the first conductive type on a part of the implant layer **122***a* shown in FIG. **11**, which is exposed by the first photoresist layer **510**, by using the first photoresist layer **510** as a mask. Here, the part of the implant layer **122***a* of FIG. **11** that is covered by the first photoresist layer **510** is the first region **122**. After the second ion implant process Imp.**2**, the first photoresist layer **510** may be removed via a strip process.

Referring to FIGS. **11** and **12**, the first and second regions **122** and **124** of the second FS layer **120** are formed via the first and second ion implant processes Imp.**1** and Imp.**2**. The impurity ions of the first conductive type may be injected into the first region **122** via the first ion implant process Imp.**1**, and the impurity ions of the first conductive type may be injected into the second region **124** via the first and second ion implant processes Imp.**1** and Imp.**2**. Thus, the impurity concentration of the second region **124** may be higher than that of the first region **122**.

A diffusion and/or activation process may be performed via a thermal process while forming the second FS layer **120**. A diffusion process may be omitted according to cases. The diffusion and/or activation process via the thermal process may be performed after the first ion implant process Imp.**1** and after the second ion implant process Imp.**2**, or only after the second ion implant process Imp.**2**.

Referring to FIG. **13**, the drift region **130** is formed by growing an epitaxial layer of the first conductive type on the second FS layer **120**. The drift region **130** may have a lower impurity concentration than the semiconductor substrate **100**. The drift region **130** may be formed by growing an N-type epitaxial layer having a suitable impurity concentration for a breakdown voltage of an N-type power device, for example, an FS-IGBT. A thickness of the drift region **130** may differ according to a breakdown voltage required by an FS-IGBT. For example, when a breakdown voltage of the FS-IGBT is required to be about 600 V, the thickness of the drift region **130** may be about 60 μm.

An impurity concentration may be adjusted while epitaxially growing the drift region **130**. Accordingly, an impurity concentration profile of the drift region **130** may be constant or may vary in a depth (or thickness) direction thereof. In other words, the impurity concentration profile of the drift region **130** may vary based on an intention of a designer. For example, the impurity concentration of the drift region **130** may be uniform according to depth.

Referring to FIG. **14**, the base region **140** is formed by selectively implanting impurity ions of the second conductive type that is different from the first conductive type, for example, P-type impurity ions, into a certain upper surface region of the drift region **130**, and diffusing and/or activating the impurity ions. The base region **140** may be, for example, a P-type high concentration (P+) impurity region, and may form a P-N junction region with the drift region **130**.

The emitter region **150** is formed by selectively implanting impurity ions of the first conductive type, for example, N-type impurity ions, into a certain upper surface portion in the base region **140**, and diffusing and/or activating the impurity ions. The emitter region **150** may be, for example, an N-type high concentration (N+) impurity region. Here, the diffusing may be performed during a thermal process performed after injecting the impurity ions.

Referring to FIG. **15**, the emitter electrode **200** is formed to contact the base region **140** and the emitter region **150** after forming the emitter region **150**. Also, the gate insulating layer **310** is formed on a surface region of the drift region **130** and parts of top surfaces of the base and emitter regions **140** and **150**, and the gate electrode **300** is formed on the gate insulating layer **310**. The gate electrode **300** may set a channel in a part of the base region **140** between the drift region **130** and the emitter region **150** by applying a voltage to the gate electrode **300**.

After forming the emitter and gate electrodes **200** and **300**, an insulating layer (not shown) and/or a passivation layer (not shown) may be further formed to cover the emitter and gate electrodes **200** and **300**.

Referring to FIG. **16**, the first FS layer **110** is formed by removing a part of the semiconductor substrate **100** of FIG. **15**. In other words, in a power device, for example, an FS-IGBT, the first FS layer **110** substantially has a smaller thickness than the drift region **130**, but the current semiconductor substrate **100** is very thick. Thus, the thickness of the semiconductor substrate **100** is reduced by grinding a rear surface thereof. Since a collector region is to be formed below the first FS layer **110**, a remaining thickness of the semiconductor substrate **100** after grinding is set by considering a thickness of the collector region. For example, when the thickness of the drift region **130** is about 110 μm, the remaining thickness of the semiconductor substrate **100** may be from about 5 to 15 μm. Here, the thickness of the collector region may be very thin, for example, from about 0.3 to about 1 μm. However, the remaining thickness after grinding and the thickness of the collector region are not limited thereto.

The first FS layer **110** is formed by grinding the rear surface of the semiconductor substrate **100** while considering such a remaining thickness. Since the first FS layer **110** is formed by grinding the rear surface of the semiconductor substrate **100** as such, a high energy ion injection process for an FS layer and an accompanying annealing diffusion process may not be performed. Also, since the second FS layer **120** is already formed on the upper region of the semiconductor substrate **100** by implanting impurity ions, the first FS layer **110** based on the semiconductor substrate **100** may have a sufficiently small thickness.

Also, since the semiconductor substrate **100** maintains a sufficient thickness until the grinding process, the semiconductor substrate **100** sufficiently operates as a support substrate while forming the base and emitter regions **140** and **150**, the emitter electrode **200**, the gate electrode **300**, and following insulating layers. Thus, process limitations that may be generated when a thin substrate is used, for example, a substrate rolling phenomenon or thermal process limitations for preventing the substrate rolling phenomenon, may be resolved.

Referring to FIG. **17**, the collector region **160** is formed on the rear surface of the first FS layer **110** by performing a third ion implant process Imp.**3** for implanting impurity ions of the second conductive type opposite to the first conductive type, for example, P-type impurity ions, on the grinded surface of the first FS layer **110**, and annealing and diffusing the impurity ions. Here, an impurity concentration of the collector region **160** may be determined according to a switching off characteristic of a device. The collector region **160** may be, for example, a P-type high concentration (P+) impurity region, and may have a thin thickness that is lower than or equal to 1 μm.

In the current embodiment, the second FS layer **120** is formed separately from the first FS layer **110** based on the semiconductor substrate **100**. Thus, the impurity concentration of the collector region **160** formed on the bottom surface of the first FS layer **110** may be somewhat freely adjusted. In other words, since the second FS layer **120** is separately formed on the first FS layer **110** via an ion implant process in the current embodiment, a contradiction between a requirement that an FS layer needs to have a high concentration to improve functions and a requirement that an FS layer needs to have a low concentration to form a collector region therebelow is resolved.

Next, the power device **1000***a*, for example, an FS-IGBT, is manufactured by forming the collector electrode **400** on the bottom surface of the collector region **160** as shown in FIG. **5**A.

FIGS. **18** through **20** are cross-sectional views for describing a method of manufacturing a power device, according to another embodiment. In detail, the power device **1000***b* of FIG. **5**B is manufactured by using the method of FIGS. **18** through **20**. Descriptions that are already provided of the method of FIGS. **9** through **17** are omitted.

Referring to FIG. **18**, the second FS layer **120**, the drift region **130**, the base region **140**, and the emitter region **150** are formed on the semiconductor substrate **100**. An area of the drift region **130** that is exposed between the base region **140** and the emitter region **150**, which are adjacent to each other, may be smaller than an area of the drift region **130** shown in FIG. **14**, and the second FS layer **120**, the drift region **130**, the base region **140**, and the emitter region **150** are formed in the same manner described above with reference to FIGS. **9** through **14**.

Referring to FIG. **19**, the trench T is formed in an upper portion of the drift region **130** by removing a portion of the surface of the drift region **130** to a predetermined depth to form an accommodation space. The trench T may be formed via a photolithography process or an etching process.

Here, the trench T has a side wall adjacent to one of the side walls of the base and emitter regions **140** and **150**.

Referring to FIG. **20**, the gate insulating layer **310***a* is formed on an inner surface of the trench T to cover the inner surface of the trench T. Then, the gate electrode **300***a* is formed in the accommodation space of the trench T where the gate insulating layer **310***a* is formed. Also, the emitter electrode **200** is formed to contact both the base and emitter regions **140** and **150**.

In FIG. **20**, the gate insulating layer **310***a* is formed to cover the top surface of the emitter region **150**, but the gate insulating layer **310***a* may not be formed on the top surface of the emitter region **150** according to cases. A top portion of the gate electrode **300***a* may form the same plane as a top surface of the drift region **130** or a top surface of the gate insulating layer **310***a* as shown in FIG. **20**, or alternatively, may protrude further than the top surface of the drift region **130** or a top surface of the gate insulating layer **310***a*.

Then, the first FS layer **110** and the collector region **160** are formed in the same manner described with reference to FIGS. **16** and **17**, and the collector electrode **400** is formed on the bottom surface of the collector region **160**, as shown in FIG. **5**B, to manufacture the power device **1000***b*, for example, an FS-IGBT.

The power device **1000***c* of FIG. **6** may be formed by using the method of FIGS. **9** through **20**, except for the arrangements of the first and second regions **122** and **124**, and thus details thereof are omitted here.

The power devices **1000***d*, **1000***d*-**1**, and **1000***d*-**2** of FIGS. **7**A through **7**C may be formed by using the method of FIGS. **9** through **20**, except for the arrangements of the first and second regions **122** and **124** and the edge termination structure ET, and thus details thereof are omitted here.

FIGS. **21** through **23** are cross-sectional views for describing a method of manufacturing a power device, according to another embodiment. In detail, the power device **1000***e* of FIG. **8** is manufactured by using the method of FIGS. **21** through **23**.

Referring to FIG. **21**, the first FS layer **110**, the second FS layer **120**, the drift region **130**, and the power device cell C

are formed by using the method described above with reference to FIGS. **9** through **16** or **18** through **20**.

The first region **122** is formed in the first active region AR**1**, and the second region **124** is formed in the second active region AR**2**. Also, the plurality of power device cells C may be all formed on the first and second active regions AR**1** and AR**2**.

Referring to FIG. **22**, a preliminary collector region **162***a* is formed by performing a third ion implant process Imp.**3** for implanting impurity ions of the first conductive type, for example, N-type impurity ions, on the grinded surface of the first FS layer **110**.

Referring to FIGS. **22** and **23**, a second photoresist layer **520** **162***a* is formed on the preliminary collector region **162***a* to cover a part of the preliminary collector region **162***a*. The second photoresist layer **520** may be formed via a photolithography process. The part of the preliminary collector region **162***a* that is covered by the second photoresist layer **520** may be the first collector region **162** of FIG. **8**.

Then, the second collector region **164** is formed by performing a fourth ion implant process Imp.**3** for implanting impurity ions of the second conductive type on a part of the preliminary collector region **162***a* that is exposed by the second photoresist layer **520**, by using the second photoresist layer **520** as a mask. Here, the part of the preliminary collector region **162***a* that is covered by the second photoresist layer **520** is the first collector region **162**. After the fourth ion implant process Imp.**3***b*, the second photoresist layer **520** may be removed via a strip process.

The amount of impurity ions of the second conductive type injected through the fourth ion implant process Imp.**3***b* compensates for the impurity concentration of the preliminary collector region **162***a* of the first conductive type such that the second collector region **164** is of the second conductive type.

Since the impurity ions of the first conductive type are additionally implanted into the first FS layer **110** of the first conductive type in the first collector region **162**, the first collector region **162** may have a higher impurity concentration than the first FS layer **110**.

Also, the second collector region **164** may have a higher impurity concentration than the first collector region **162**. For example, when the first collector region **162** is an N+ type impurity region, the second collector region **164** may be a P++ type impurity region.

An annealing process for diffusion and/or activation may be performed after the fourth ion implant process Imp.**3***b* or after the third and fourth ion implant processes Imp.**3***a* and Imp.**3***b*.

As described above, in a power device and a method of manufacturing the same, according to the one or more of the above embodiments of the present invention, high speed switching is possible since a current tail of holes is reduced during turn off switching. Also, an impurity concentration of an FS layer may be elaborately and easily controlled since a part of the FS layer is formed by implanting impurity ions. In addition, by elaborately adjusting an impurity concentration, a thickness and impurity concentration profile of the FS layer may be variously adjusted. Furthermore, hole injection may be reduced by forming the part of the FS layer via an ion implant process to have first and second regions having different impurity concentrations. Accordingly, the power device may have a high speed switching characteristic by remarkably improving electric characteristics, for example, an on-off switching waveform.

An impurity concentration of a collector region may be easily adjusted since a part of the FS layer is formed via the ion implant process separately from a part of the FS layer based on a semiconductor substrate. Also, since a part of the FS layer is formed by grinding a rear surface of the semiconductor substrate, a high energy ion injection process and an accompanying annealing diffusion process are not required.

Also, since the part of the FS layer formed via the ion implant process may include the first and second regions having different impurity concentrations and a ratio of areas and arrangements of the first and second regions may be adjusted, an amount of holes injected from the collector region to a drift region and a path of the holes may be freely adjusted. Accordingly, crowding of an electric field is reduced, thereby preventing a breakdown voltage of the power device from decreasing. Also, since an edge termination structure may occupy a relatively less area, more power device cells may be formed in the power device having the same area, and thus the power device may have a higher driving current.

Also, the part of the FS layer formed via the ion implant process may make it possible to realize a bi-mode IGBT without having to align the rear surface of the semiconductor substrate (which is difficult to achieve), by using the first and second regions having different impurity concentrations.

While one or more embodiments of the present invention have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

What is claimed is:

1. A method of manufacturing a power device, the method comprising:

performing a first ion implant process by implanting impurity ions of a first conductive type into a front surface of a semiconductor substrate to form an implanted first field stop layer, the semiconductor substrate being the first conductive type;

performing a second ion implant process by implanting impurity ions of the first conductive type into a first part of the implanted first field stop layer such that an impurity concentration of the first part of the implanted first field stop layer is higher than an impurity concentration of a second part of the implanted first field stop layer;

forming a drift region by growing an epitaxial layer having an impurity concentration that is lower than the semiconductor substrate on the implanted first field stop layer;

forming a plurality of power device cells on the drift region;

forming a second field stop layer by grinding a rear surface opposite to the front surface of the semiconductor substrate; and

forming a collector region below the second field stop layer.

2. The method of claim **1**, wherein the performing of the second ion implant process includes:

forming a first photoresist layer covering a first region of the implanted first field stop layer;

implanting impurity ions of the first conductive type into a second region of the implanted first field stop layer exposed by the first photoresist layer, by using the first photoresist layer as a mask; and

removing the first photoresist layer.

3. The method of claim 2, wherein the forming of the plurality of power device cells includes forming the plurality of power device cells on the first region of the implanted first field stop layer.

4. The method of claim 2, wherein the second region surrounds the first region at a constant depth, and

the method further comprises forming an edge termination structure on the drift region and on the second region to surround the plurality of power device cells.

5. The method of claim 1, wherein the forming of the plurality of power device cells includes:

forming a base region of a second conductive type that is different from the first conductive type on a surface region of the drift region;

forming an emitter region of the first conductive type on a surface region of the base region;

forming a gate electrode adjacent the drift region, the base region, and the emitter region such that a gate insulating layer is disposed between the gate electrode and each of the drift region, the base region, and the emitter region; and

forming an emitter electrode on the base region and the emitter region.

6. The method of claim 1, wherein the forming of the plurality of power device cells includes:

forming a base region of a second conductive type different from the first conductive type on a surface region of the drift region;

forming an emitter region of the first conductive type on a surface region of the base region;

forming a trench adjacent to one of a plurality of side surfaces of the base region and the emitter region, and having an accommodation space therein by removing a portion of a surface of the drift region to a depth;

forming a gate insulating layer covering an inner surface of the trench;

forming a gate electrode in the trench where the gate insulating layer is formed; and

forming an emitter electrode on the base region and the emitter region.

7. The method of claim 1, wherein the forming of the collector region includes forming the collector region by implanting impurity ions of a second conductive type different from the first conductive type.

8. The method of claim 1, wherein the forming of the collector region includes:

performing a third ion implant process by implanting impurity ions of the first conductive type on the rear surface of the semiconductor substrate; and

performing a fourth ion implant process by implanting impurity ions of a second conductive type different from the first conductive type into a part of the rear surface of the semiconductor substrate such that a part of the collector region is in a conductive type different from a remaining part of the collector region.

9. The method of claim 8, wherein the performing of the fourth ion implant process includes:

forming a second photoresist layer to cover a part of the rear surface of the semiconductor substrate;

implanting impurity ions of the second conductive type into a remaining part of the rear surface of the semiconductor substrate exposed by the second photoresist layer, by using the second photoresist layer as a mask; and

removing the second photoresist layer.

10. A method of manufacturing a power device, comprising:

forming a first field stop layer of a first conductive type;

forming, using a first ion implant process, a first part of a second field stop layer,

forming, using a second ion implant process, a second part of the second field stop layer, the first part having an impurity concentration higher than an impurity concentration of the second part, the second field stop layer being disposed on the first field stop layer and being of the first conductive type;

forming a drift region by growing an epitaxial layer on the second part of the second field stop layer and of the first conductive type, the drift region having an impurity concentration lower than an impurity concentration of the first field stop layer;

forming a plurality of power device cells on the drift region; and

forming a collector region below the first field stop layer.

11. The method of claim 10, wherein the first part contacts the second part.

12. The method of claim 10, wherein the first part and the second part are alternately disposed along a horizontal direction.

13. The method of claim 10, wherein the second part surrounds the first part at a constant depth.

14. The method of claim 10, further comprising:

forming an edge termination structure on the drift region and above the second part, the edge termination structure surrounding the plurality of power device cells.

15. The method of claim 10, wherein the collector region is of a second conductive type that is different from the first conductive type.

16. The method of claim 10, wherein the collector region includes a first collector region of the first conductive type and a second collector region of a second conductive type that is different from the first conductive type.

17. The method of claim 10, wherein the second field stop layer has an impurity concentration that increases from the first field stop layer to reach a maximum impurity concentration and then decreases towards the drift region.

18. The method of claim 10, wherein the first field stop layer and the drift region each have a uniform impurity concentration profile in a depth direction.

19. The method of claim 10, wherein the first field stop layer is formed by grinding a rear surface of a Czochralski (CZ) single crystal substrate.

20. The method of claim 10, wherein the drift region is formed on the second field stop layer via an epitaxial growth.

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